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THE INSIDE OF ELECTRICAL MACHINES

THE INSIDE OF ELECTRICAL MACHINES

by

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ERNEST BENN LIMITED
LONDON

First published 1949

Published by ERNEST BENN LIMITED
Bouverie House, Fleet Street, London, E.C.4
Printed in Great Britain by BRISTOL TYPESETTING COMPANY
Bristol and London

FOREWORD

The series of articles in *The Electrician* which dealt with "The Inside of Electrical Machines" created such widespread interest, both in this country and overseas, that their expansion and reproduction in book form is a valuable service to the industry. By his close attention to detail and by his exhaustive researches into the sources of supply of materials used in electrical machines, Mr. R. H. Robinson has provided information of a type to be found in no other single volume. The engineering experience upon which the subject matter is based is given practical expression in electrical machines—large and small—all over the world, and, offered at a time when the electrical industry is so heavily engaged in the manufacture of power plant, this book will be welcomed by every engineer concerned with electrical machine design.

There has been absorbed by the electrical industry during the last few years a group of engineers who were prevented from entering the manufacturing side of engineering at an age which they would have done in other days, and to them this book will be an invaluable reference. The older engineer will find in its pages an easy way of keeping fresh in memory facts about electrical materials, which under present-day conditions of manufacture are inclined to become clouded over; while the university or college student is offered by the publication of this book advantages which his forebears were not privileged to enjoy.

STANLEY G. RATTEE, A.M.I.E.E.
Editor, *The Electrician.*

August, 1948.

ACKNOWLEDGEMENTS

This book is based upon a series of articles which the author wrote for *The Electrician* in 1946. Opportunity has been taken to re-write and add to much of the material as it originally appeared. In compiling it, the writer has endeavoured to give a comprehensive survey of the subject, based upon long experience.

The author would like to acknowledge his indebtedness to the British Standards Institution for permission to quote so freely from their publications.

Thanks are due to the following firms which have supplied illustrations or information, and in many cases allowed the author to visit their works and study the processes.

Richard Thomas & Baldwins Ltd.	Electrical Sheet Steel.
The Bushing Co., Ltd.	Synthetic Paper Tubes.
B. & F. Carter & Co., Ltd.	Braiding Machines.
British Celanese Ltd.	Fortisan Rayon.
Courtaulds Ltd.	Tenasco Rayon.
English Electric Co., Ltd.	Electrical Machines.
Fibreglass Ltd.	Fibrous Glass.
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The Sterling Varnish Co., Ltd.	Insulating Varnishes.
British Thomson-Houston Co., Ltd.	Electrical Machines.
H. D. Symons Ltd.	Varnished Fabrics and Tapes.
B. S. & W. Whiteley Ltd.	Pressboard and Presspaper.
Berry Wiggins & Co., Ltd.	Compounds.

Last, but not least, he wishes to acknowledge with gratitude the freedom with which he has been able to use the specifications and data of The General Electric Company Ltd., with which firm he has been happily associated for many years.

To his colleagues there, he wishes to express his grateful appreciation of their generous assistance.

R. H. ROBINSON.

Sutton Coldfield,
September, 1948.

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CHAPTER I

INSULATIONS DESCRIBED; THEIR USES IN MACHINES

Before studying insulations in detail, it will be an advantage to endeavour to define what is meant by an insulator and to understand where the different types are used in machines.

INSULATORS.

All materials conduct electricity to a greater or less degree, so that there is no fundamental distinction between insulators and conductors. In practice, however, the resistivity of satisfactory insulating materials is of the order of 10^{14} ohms/cm^3, whereas that of metals (the best conductors) is of the order of 10^{-6} ohms/cm^3. There is thus an enormous gap between good insulators and good conductors. This gap enables us to distinguish insulators from conductors for practical purposes.

It is assumed that non-metallic substances made by weaving, such as cotton, silk, rayon and glass fabrics, or others made by paper-making processes, and certain types of varnishes, are insulators. Fabrics and papers, however, are not satisfactory insulators if they absorb moisture, so this is usually prevented by certain treatments, such as drying out and varnishing with good-quality insulating varnishes.

Clear micas of various kinds are acknowledged insulators. Asbestos products may, or may not, be insulators, much depends upon the crudes from which they are made, and often upon the chemical treatment which they receive. It would be very unwise to use asbestos products for electrical purposes unless they have been specially made.

THE DISPOSITION OF VARIOUS INSULATIONS.

A section of a typical small D.C. motor is shown in Fig. 1, and the list of insulations against each letter will convey some idea of the many alternatives available for motors of say 1 to 10 h.p.

A. Armature stampings may be insulated with—
Paper pasted to one side.
Kaolin (China Clay) and water soluble gum (Insuline)
Varnish.

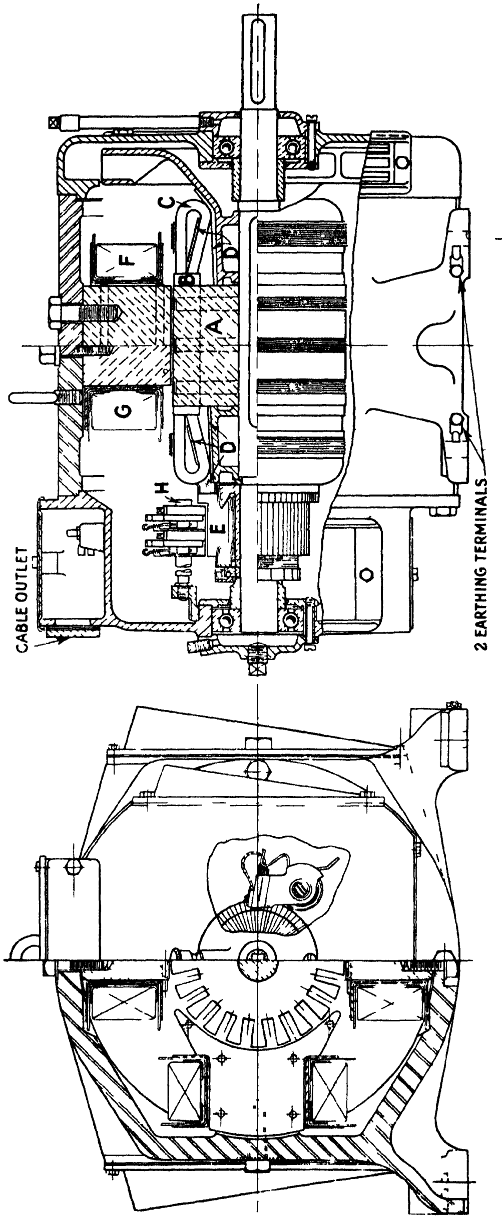

Fig 1

B. Slot liners or troughs may be of—
Varnished presspaper or leatheroid.
Varnished presspaper with varnished (Empire) cloth.
Micanite backed with presspaper.
Mica-cloth bonded with a flexible varnish.
Mica-glass cloth bonded with a special varnish.

C. The wire for the armature coils may be covered with—
Double cotton, silk, or glass.
Enamel and paper, or synthetic enamel.
Asbestos.

D. The miscellaneous insulation may be of more than one type chosen from—
Varnished pressboard or leatheroid.
Micanite bonded with shellac or a flexible varnish.
Mica-presspaper, mica-cloth, mica-glass.

E. The commutator contains—
Segment micanite and moulding micanite.

F. Field coils may be wound with—
Wire insulated as described in *(C)* or Wire covered with ordinary enamel.
The spools for the coils may be of
Varnished pressboard.
Micanite.
Alternatively the coils may be taped all over in which case spools may not be used.

G. Interpole coils may be wound with—
Wire or strip insulated with double cotton or glass, or asbestos.
Bare strip, with insulation in ribbon form fed in as the coils are wound.
There may be spools or overall taping as described in *(F)*.

H. Brush spindles may be insulated with—
Micanite, synthetic resin paper, or moulded plastics.

J. The terminal blocks may be of—
Synthetic resin paper or fabric boards.

The following items also have to be considered—

1. Varnishes for impregnating and finishing.
   These may be—
   Oil base, synthetic, or spirit.
2. Bitumen for impregnating certain types of field and interpole coils.
3. Cables; these may be insulated with—
   Vulcanised rubber, tough rubber, varnished cambric or polyvinyl chloride, commonly known as P.V.C.

The foregoing list does not cover everything. Other kinds of insulation are required when dealing with large machines, notably varnished cotton tape, mica tape and micafolium. These will be reviewed in later pages.

Such an array of alternatives is very confusing. The position may be simplified, however, by separating the items into two groups, class A and class B, as defined in a number of British Standard Specifications or British Standards; the latter being the name used for new publications or revisions of old ones.

BRITISH STANDARD SPECIFICATIONS.*

These publications cover an extremely wide range of material and subjects. Each specification or Standard is compiled by a committee of experts upon the subject of the specification. These experts are drawn from most sections of the industries concerned, and from the users.

Thus, the Specifications are, in general, ideal. It will be to the benefit of manufacturer and user alike to work to them when available and avoid the use of home-made purchasing specifications. In due course relevant British Standards will be discussed in some detail.

There are eight British Standard Specifications for electrical machines. Their titles will be found near to Table 1 in the next chapter.

CLASSIFICATION OF INSULATING MATERIALS.

In each of the British Standards for machines, the following definitions of insulating materials, and explanations relative to mixed insulations are given. The Classification is that officially adopted by the International Electrotechnical Commission in 1935.

CLASS A. Cotton, silk, paper and similar organic materials when impregnated or immersed in oil, also the substance known as enamel applied to enamelled wire.

NOTE.—Impregnated Cotton, Paper or Silk (also Compound-treated Insulation).—An insulation is considered to be "impregnated" when a suitable substance replaces the air between its fibres. The impregnating substance, in order to be considered suitable, must have good insulating properties; must entirely cover the fibres and render them adherent to each other and to the conductor; must not produce interstices within itself as a consequence or evaporation of the solvent or through any other cause; must not flow at the temperature limit specified; must not unduly deteriorate under prolonged action of heat.

CLASS B. Mica and asbestos and similar inorganic materials in built-up form combined with binding cement. If Class A material is used in small quantities for structural purposes only, in conjuction with Class B insulation, the combined materials may be considered as Class B, provided the electrical and mechanical properties of the insulated winding are not impaired by the application of the temperature per-

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*Obtainable from: The British Standards Institution, Publication Dept.,
28 Victoria Street, London, S.W.1.

mitted for Class B material. (The word "impair" is here used in the sense of causing any change which could disqualify the insulating material for continuous service).

INSULATION MADE UP OF DIFFERENT MATERIALS.

When the insulation is made up of different materials (except in those cases defined under Class B) the temperature rise attained by each material shall not exceed the limit permitted for that material.

EXAMPLES :—

(a) When different insulating materials are used on various parts of one winding (for instance, in the slot and for the end windings) the limit of temperature-rise applicable to any part of the winding is that set for the insulation used on the part.

(b) When the insulation on any part consists of superposed layers of insulating materials falling in different classes (for instance superposed layers of Class A and Class B material) the two following cases arise—

(i) If it is possible to measure the temperatures attained by the various layers, each of the materials is entitled to the temperature rise which is assigned to it.

(ii) If it is not possible to measure the temperatures attained by the various layers, the temperature-rise applicable to the part of the winding under consideration is to be taken as that for the insulating material with the lowest limit.

With the foregoing definitions it is not difficult to separate many of the insulations into one of the two classes which have been defined. It may not be easy to decide the classification of mixed insulations in all cases. Broadly speaking it may be said that built up insulation containing mica in fair quantity will rank as class B.

On the other hand a stator winding in which the coils are wound with cotton covered strip would be class 'A,' even though the overall insulation consisted of moulded mica tubes on the slot portion and mica tape in the end winding.

CHAPTER II

WORKING TEMPERATURES; LIFE OF INSULATION

PERMISSIBLE TEMPERATURES FOR INSULATION.

Insulations deteriorate with heat, and for this reason the temperature of machines must be confined to some figure which will not cause too rapid deterioration.

The use of class A material in the make-up of class B is undesirable, but cannot be avoided in most instances. Since the mica must be used in the form of flakes or splittings they have to be bonded to some suitable material, such as paper, silk, cloth, etc., so that they can be applied to coils or various parts of windings.

Slightly higher temperatures are permitted for this type of insulation, chiefly because the mica will form an unalterable barrier against electrical breakdown in the event of the class A material losing some of its insulating value.

It is now possible to use fibre glass fabric for the backing material, and synthetic varnishes for bonding, thus permitting the insulation to be worked at still higher temperatures. However, such combinations are considered special at present and are not much used although the demand is increasing. There are no British Standards covering this type of insulation, and the temperature at which such insulations may be run is a matter for agreement between manufacturers and users. Further discussion on this subject will be found in later chapters.

The various British Standards give permissible rises in temperature above the ambient temperature at the end of certain specified load runs. The ambient temperature is that of the surrounding air, or the cooling air in the case of machines having closed air circuits and coolers. The maximum ambient temperature for the tests is specified as 25°C. for traction machines and 40°C. for all other machines.

It is the total temperature, not the temperature rise which effects the life and safety of insulation. This figure is ascertained by adding the permitted rise to the specified ambient. It varies in the different Standards, and a representative list is given in Table 1. It does not include all types of windings, but the selection has been made to enable as fair a comparison as possible to be made. A list of the titles of the Standards is given immediately before Table 1 so that all necessary information is together.

Table 1.—Maximum Temperatures for Electrical Machines.

168—1936. Electrical Performance of Industrial Electric Motors and Generators.
169—1925. Electrical Performance of Large Electric Generators and Motors.
170—1939. Electrical Performance of Fractional Horse-Power Electric Motors and Generators.
173—1941. Traction Motors and Associated Rotating Electrical Machines.
225—1925. Electrical Performance of Alternators, Steam Turbine Driven.
226—1925. Electrical Performance of Large Generators and Motors.
741—1937. Flame-proof Electric Motors.

B.S.	REMARKS	Maximum Total Temperature °C.				
		CLASS A.		CLASS B.		
		Thermom.	Resistance.	Thermom.	Resistance.	E.T.D.
168	Overloads Permitted ..	80	-	90	—	—
	Totally Enclosed ..	90	—	105	—	—
169	Overloads Permitted ..	80	85	90	105	105
170	Overloads not Permitted	90	—	—	—	—
173	Heavy Overloads Permitted ..	90	110	115	145	—
225	Overloads not Permitted	95	—	105	—	120
226	Overloads not Permitted	95	100	105	120	120
741	Totally Enclosed ..	90	—	105	—	—

NOTE.—1. For A.C. windings fully insulated for a rated voltage of over 7,000 volts, the limit of temperature rise by thermometer to be reduced by 1½°C. for each 1,000 volts or part thereof above 7,000 volts.

2. When machines are tested near sea-level and are required for service between 3,300 and 10,000 feet, the limit of temperature rise to be reduced by 1½ per cent. for each 1,000 feet above sea-level at which they are intended to work. The corrections not to apply for altitudes below 3,300 feet.

If it is known that any machines have to work in ambient temperatures above those specified, they are designed for lower temperature rises so that the final total temperatures do not exceed those in Table 1.

It is possible to give explanations for some of the variations shown in Table 1, but not all; the comments which follow will help towards a better understanding of the figures.

A. Machines with Class A insulation to BS. 168 and 169 are permitted sustained overloads of 25% for periods of ¼ to 2 hours, depending upon their size. If these overloads come on after machines have attained their permitted temperature when running on full load it is considered that the final temperature will be in the neighbourhood of 90°C. when measured by thermometer.

B. Totally enclosed machines to BS. 168 and 169 are not considered capable of carrying sustained overloads. For this reason their final temperature is fixed at the same as that which non-totally enclosed machines are expected to attain after the specified overloads, viz. 90°C. when measured by thermometer.

C. Fractional horse-power machines are not designed for sustained overloads. They are consequently permitted to attain 90°C.

D. Traction motors are in a class apart from all others. In service their loads are continually varying over a wide range, depending upon the gradients, crush loading, wind, and so forth. It is recommended in BS. 173 that the temperatures shown in Table 1 should not be exceeded under the most adverse conditions expected in service. The very high temperature of 145°C. would not be expected to occur very often.

By considering gradients and other relevant matters designers endeavour to avoid very high temperatures by employing motors having ample power.

E. Machines to BS. 225 and 226 are not permitted sustained overloads. It is not possible to give an explanation why the permissible temperature is 95°C. as against 90°C. in other cases.

F. Temperatures obtained by resistance are invariably given as being higher than those measured by thermometer.

G. If it is remembered that machines to BS. 169 are permitted sustained overloads whereas those to BS. 225 and 226 are not, the reason for the 15°C. difference for class B insulation is apparent.

TEMPERATURE MEASUREMENTS.

Three methods of measuring temperature are recognised—
(a) By thermometer, (b) by the alteration in the resistance of windings with increasing temperature, (c) by the use of Embedded Temperature Detectors. The latter is usually referred to as the E.T.D. method.

Due to heat being detrimental to the long life of insulation, it is important that methods for measuring temperature should be known. The descriptions which follow are taken from BS. 169-1925.

THERMOMETER METHOD.

When the Thermometer method is used, the temperature of the machine shall be measured by thermometers applied to the hottest accessible surfaces of the stationary parts of the machine during the test period, and by other thermometers applied to the accessible surfaces of the rotating parts as soon as the machine is stopped after the test.

The term "Thermometer" includes mercury and alcohol bulb thermometers.

When bulb thermometers are employed in places where there is any varying or moving magnetic field, alcohol thermometers should be used in preference to mercury thermometers as the latter are unreliable under these conditions.

In all cases the bulb of the thermometer, except at the point of contact, shall be covered with a pad of felt, cotton wool or other non-conducting material $\frac{1}{8}$ in. thick extending at least three-quarters of an inch in every other direction from the bulb and pressed into contact with the surface to which this is applied, to prevent loss of heat by radiation and convection from the bulb.

RESISTANCE METHOD.

In this method the mean temperature rise of the windings shall be determined by the increase in the resistance of the windings themselves, and checked by thermometers applied to the accessible surfaces of the windings to ascertain whether there is any higher local temperature. The highest of the temperatures thus found shall be taken as the temperature by the resistance method.

The temperature of the windings as measured by thermometer before commencing the test should not differ from that of the cooling medium. The initial resistance and initial temperature of the windings shall be measured at the same time.

NB.—Since the resistance of copper over the range referred to in this specification varies in direct proportion to the temperature (above minus 234.5°C.) the ratio of hot to cold temperatures may be obtained from the ratio of the resistances by the formula—

$$\frac{R_2}{R_1} = \frac{T_2\ ^\circ C + 234.5}{T_1\ ^\circ C + 234.5} \quad \text{where}$$

R_2 = Resistance of windings hot.
R_1 = Resistance of windings cold.
T_2 = Temperature of windings hot.
T_1 = Temperature of windings cold.

EMBEDDED TEMPERATURE DETECTOR METHOD.

Embedded Temperature Detectors are resistance thermometers or thermo-couples built into the machine during construction at points which are inaccessible when the machine is completed. This term does not include the necessary measuring instruments.

When the internal temperature of a machine is to be measured by Embedded Temperature Detectors, at least six detectors should be built into the machine, suitably distributed around the circumference within the slots, all reasonable efforts consistent with safety being made to place the Embedded Temperature Detectors at the various points at which the highest temperatures are likely to occur.

(a) When the winding has more than one coil per slot, the detector is placed between the upper and lower coils in the slot.
(b) In the case of a winding having only one coil per slot, the detector is placed between the outside of the coil and the insides of the slot lining at the bottom of the slot.

Position of Embedded Detectors.

Care must be exercised in the placing of embedded temperature detectors, especially in high voltage machines. They should always be fixed in contact with coils which are connected to the neutral point so as to avoid the danger of shock if the coil insulation fails. When attaching them to end windings it is not enough merely to tape them to coils near the neutral, insulation additional to that on the coils must be inserted between temperature detectors and the coil insulation.

The Life of Insulation.

The life of insulations, especially those in machines, is affected by many factors, namely temperature, moisture, dirt, relative movement due to expansion and contraction, vibration, and in some cases electrical stress.

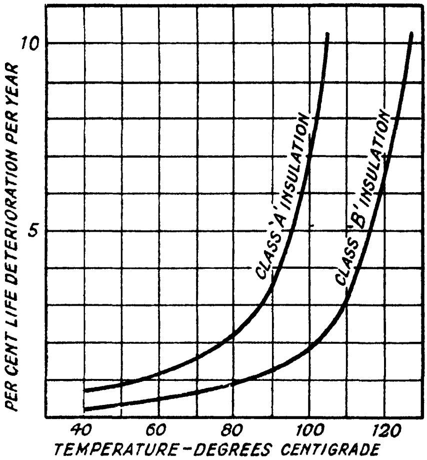

Fig. 2—Curves showing annual percentage dissipation of the life of insulating materials.

All investigators appear to agree that temperature is by far the predominating cause of failure. W. A. Tripp (1) states that experience confirms that the efficacy of insulation is best judged by its decrease in mechanical strength due to heat rather than its electrical qualities. The theory behind this is that electrical breakdown does not normally occur because the insulation has lost its ability to withstand a particular voltage, but because a physical flaw has developed.

Curves showing the effect of temperature in reducing the life of machines are given in the article and the relevant ones are reproduced in Fig. 2.

An approximate way of assessing the life of insulation is given by a rule-of-thumb which says that the thermal life of insulation is halved for each 10°C. rise in working temperature, and doubled for each 10°C. reduction (2). To remember this rough approximation may prove useful at times.

1. Temperature Records as an Aid to Depreciation Study. W. A. Tripp. Electrical Engineering (A.I.E.E.), Feb., 1947. Page 182.
2. Synthetic Insulation and the 10-Degree Rule. G. L. Moss. Westinghouse Engineer. July, 1945. Page 106.

CHAPTER III

MANUFACTURE OF ELECTRICAL SHEET STEEL: INSULATION OF THE LAMINATIONS

Whilst it is not the purpose of this book to deal with the manufacture of the ordinary metallic parts in electrical machines, there are some of special interest. The manufacture of electrical sheet steel comes in this category.

Silicon steel has been used for this purpose since the discovery by Sir Robert Hadfield and his co-workers of the beneficial effect of silicon in reducing the hysteresis and increasing the resistivity of iron of commercial purity. The resistivity controls the eddy current loss in alternating fields.

FIG. 3—Sheet bars being delivered from the furnace.

The amount of silicon varies according to requirements. For armatures 0.2 to 0.3 per cent is usual, for large A.C. stators the percentage is about 1.5, and for turbo-alternators it is as high as 2.5 to 3.0 per cent. The method of manufacture is very much the same for all the grades of hot rolled silicon steels, the major difference being in the temperature of rolling, which is progressively higher with increasing percentages of silicon.

CONVERTING INGOTS INTO "SHEET BARS."

Most of the grades of steel are refined in the basic open hearth furnace. The steel is cast into ingots varying in weight from 10 cwt. to 4-5 tons, German practice favouring small ingots and American, large ingots. English practice in this respect is somewhere between the two. These ingots are reheated and rolled into a bar of section roughly ½ × 10 ins., and the resulting "sheet bar" is sheared into lengths equal to the width of the sheet which it is desired to produce.

ROLLING THE SHEETS.

The bars are reheated in a furnace, nowadays usually gas fired, with a mechanical arrangement for conveying the bars in pairs through the heating zone of the furnace and discharging them to the roller. Fig. 3 is an illustration of the discharge end of such a furnace, in this case with walking beam conveyor system. The various stages of rolling are depicted in Fig. 4 where A represents a cross-section of a sheet bar.

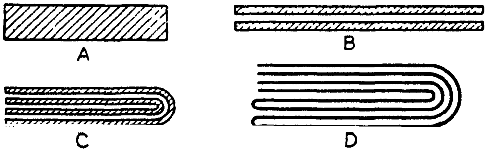

FIG. 4—Stages in the rolling of sheets from bars.

The bars are rolled in two or three high hot mills with chilled iron rolls, so that the width is gradually increased and the thickness decreased. It is usually not possible to reduce the thickness below 0.10 in. in this type of mill, and when this thickness is reached a pair of sheets are "matched" together (Fig. 4 B) and rolled again until their combined thickness is 0.10 in. Two sheets being rolled together are shown in Fig. 5.

After this stage they are doubled, as shown in Fig. 4 C, reheated in a similar type of furnace to the full rolling temperature and given a sufficient number of passes through the mill to again reduce the total thickness to approximately 0.10 in. In the case of sheets .014 in. in thickness, the doubling, reheating and rolling process is again repeated, see Fig. 4 D. The gauge of the sheets is controlled by the weight per foot of length of the original bar, and the final length of the finished pack of sheets which is adjusted in rolling to a predetermined figure. The original bar is of course of such a weight that the gauge will be correct.

FIG. 5—Rolling electrical steel sheets in pairs.

The finished pack of this gauge consists therefore of eight sheets which are held in a solid pack by the incipient welding produced during hot rolling. Thicker gauges of sheet are finished in packs with a less number of sheets in the pack. The scrap edges are sheared off in mechanical shears and the pack is " opened " *i.e.* the sheets are separated from one another by hand.

In this condition the sheets still carry the thin film of oxide produced during rolling and have poor magnetic properties because of the internal mechanical strain left by the hot rolling. It is therefore necessary to anneal them.

COLD ROLLING AND PICKLING.

Prior to annealing it is common practice to give the sheets a light pass through the cold rolls sufficient to flatten them and improve the surface. The decrease in thickness produced is so slight as to be hardly measurable. Fig. 6 illustrates a typical mill for this purpose.

The higher grades such as turbo-stator qualities are almost invariably pickled in acid prior to the cold rolling operation to remove all scale.

ANNEALING.

The final operation is the annealing process which is designed to produce the maximum grain size, to give complete removal of all rolling strains and to give a slow rate of cool so that the optimum magnetic properties are developed.

The modern type of equipment used for this purpose is normally —(a) Radiant tube furnaces, gas or oil fired. The capacity of these furnaces is usually 40/60 tons. (b) Electrically heated pit type furnaces with a hydrogen or burnt-down cracked ammonia atmosphere. Both are usually thermostatically controlled and arranged so that flexible thermo-couples can be distributed throughout the load of sheets, and the temperature of the hottest and coldest part of the load is continuously recorded during the heat treatment cycle. In this way exact control of the temperature of the whole of the charge is obtained.

FIG. 6—Cold rolling sheets before annealing.

The annealing temperature normally varies from 700°C. to 800°C. depending on the silicon percentage of the charge.

TESTING FOR MAGNETIC LOSS.

After annealing the sheet is tested for magnetic performance and the normal acceptance test is a 50 cycle A.C. magnetisation total watts loss measurement at B_{max} 10,000.

For annealing, the sheets are stacked horizontally and heated from the sides only, so that those near the top of the pack are hotter than those near the bottom. Because of this, samples for magnetic test are always taken from both the top and bottom of the pack. The number of sheets in the intermediate positions to be tested depends upon the weight of the stack.

There are three standard methods of loss testing, viz., (1) Epstein,

(2) Lloyd-Fisher and (3) Churcher. In principle they are alike in that they consist of a small transformer with a core of the material under test, the iron loss being measured by a sensitive wattmeter when a voltage is applied to the primary winding so as to give a B_{max} of the specified order.

INSULATION OF THE LAMINATIONS.

The laminations may be insulated with paper, china clay or varnish.

INSULATION WITH PAPER.

The paper used is known as coreplate paper. It is a chemical wood pulp glazed on one side, having a thickness of .0015 in. to .002 in. and a substance of not less than 26 grams per sq. metre. It is purchased in rolls of various widths and colours; the colours are used to indicate the type of sheet steel to which the paper is applied.

A rough idea of the method used in applying the paper is shown in Fig. 7. The sheets of lamination steel are fed into the feed rolls which pass them on to the papering rolls. The paste pipe has holes drilled along its under surface from which paste is fed on to the metal sheets. After passing the papering rolls the sheets are taken up by a chain conveyor and passed over a series of gas jets which dry the paste and burn off any paper protruding beyond the edges of the metal sheets.

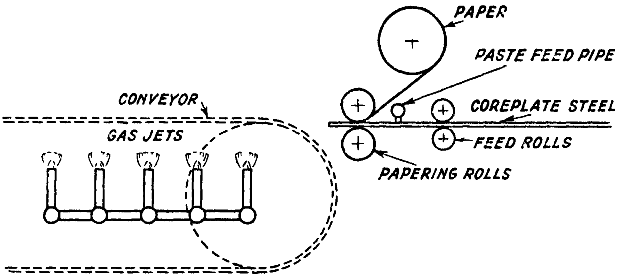

FIG. 7—Application of paper to coreplate steel.

INSULATION WITH KAOLIN.

The insulation which is composed of china clay or Kaolin is mixed with a water-soluble gum. It is sprayed on to the sheets by compressed air spray guns; several of these are fixed in a line and caused to oscillate through a small angle so as to cover the whole surace of the sheets passing beneath them on a chain an oven where heat dries the insulation; this type is often spoken of as insuline.

Removal of Burrs.

For the two methods just described the insulation is applied only to one side of the steel; in general it is applied to the sheets before they are made into laminations.

Laminations for small machines which are in continuous demand, are often punched out by dies which produce a complete lamination at one stroke. For larger machines, when the demand is not continuous, the laminations are produced by blanking out circles and then producing the teeth by punching out the slots one at a time; this latter operation is known as notching. With both methods of production, burrs are likely to be left along the edges of slots and holes and it is necessary to remove these if the iron losses are to be kept low. By carrying out punching and notching with the un-insulated face of the sheets next to the die, the burrs appear on the un-insulated side of the laminations and can be removed by passing the laminations through a grinding machine which operates on the burred face.

Insulation with Varnish.

When varnish is used it is customary to apply it after the laminations are completely made and ground since the most economical way to apply varnish is by rolls as shown in Fig. 8. This method applies a thin coat of varnish to each side of the laminations and it would cause serious clogging of the grinding wheel if varnished surfaces were ground; also, as the varnish coat is thin it is desirable that it be intact on both sides if iron losses are to be kept low. It is found in practice that this method is competitive in cost with the other two.

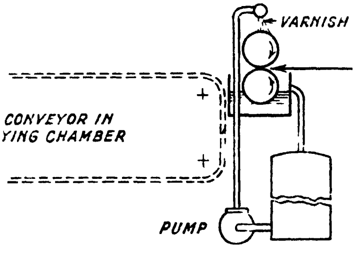

Fig. 8—Application of varnish to coreplate steel.

The application of varnish to stampings may be troublesome although the principle is very simple, as will be seen from Fig. 8. The machine consists of two driven rolls and the stampings are fed into them in the direction shown by the arrow. Varnish is pumped from a supply tank into a pipe fixed above the top roll and flows through a line of holes drilled in the pipe. The quantity of varnish is greatly in excess of what is needed for coating the stampings and this excess runs into the trough beneath the lower roll. The varnish level is kept at a suitable height by the position of an outlet pipe which conducts the surplus back to the supply tank. In this manner both faces of the stampings are coated. The chain conveyor passes through a heated chamber.

Varnish application presents several problems. The rolls may be of rubber, printers' composition or metal covered with felt. Uncovered metal rolls cannot be used as they would not give to the inequalities in the stampings and the varnish coat would be very uneven in thickness. Rubber coated rolls are very satisfactory if the varnish does not contain a solvent which attacks it. Printers' composition rolls are free from attack by most varnishes but their surfaces are soon spoiled if the stampings are not free of burrs, and they tend to leave the varnish deposit thicker at edges than on the body of the stampings. Felt rolls have given satisfaction with some varnishes but with others the hairs in the felt cause minute bubbles to form all over the varnished surfaces.

Which method is employed for insulating stampings is largely a matter of circumstance; if a factory which does its own insulating has adopted one method it usually adheres to it. All the alternatives described are employed and have given satisfaction over long periods of time.

CHAPTER IV

PRESSPAPER AND PRESSBOARD

Presspaper and pressboard may be considered as generic names for materials marketed as elephantide, fuller-board and presspahn. Such products are covered by BS. 231-1936, Pressboard for Electrical Purposes (excluding "Built up" Pressboard). It defines them as materials made by a paper-making process from vegetable fibres, but differ from papers in that they are made on an "intermittent board" machine and are afterwards subjected to great pressure in order to remove excess of water and to "close up" the material, thus producing a solid board. The boards are afterwards dried and, if so specified, are glazed by calendering and planishing.

Thicknesses up to and including 0·040 in. thick and 72 ins. wide are now made in continuous lengths, instead of on intermittent board machines, which produce lengths of about 6 feet. The continuous material, which is sold in rolls, and may be regarded as presspaper, is required to comply with the tests specified in BS. 231.

Readers are urged not to confuse leatheroid with pressboard. Although similar in the early stages of manufacture the latter material is subjected to entirely different processes later, and the final product is completely different. Comparison of the two will be made after describing leatheroid in detail in the next chapter.

QUALITIES IN GENERAL USE.

Three qualities of pressboard and presspaper are in general use. In BS. 231 they are known as types I, II, and V. It is important to remember that we refer to the grading as given in B.S. 231, since some manufacturers grade their products differently. For information it may be stated that Type III is a pressboard impregnated during manufacture with varnish, oil or wax. It is not included in BS. 231. Type IV is very hard and little used in machines.

TYPE I is usually of a brown or buff colour and made chiefly of jute fibres. It is hard, non-porous, with a density of not less than 1.15 gms. or more than 1.30 gms. per cu. cm. after 18 hours drying at 80°C. It has good electric strength and is useful for general purposes. It is the cheapest of the three grades.

Type II is grey in colour and is made of a mixture of jute and cotton fibres. It is soft and porous with a density of 0·90 to 1·15 gms. per c.c. It has a lower electric strength than type I, but in view of its greater flexibility and better ageing properties, and the readiness with which it will take varnish, it is most frequently used for insulating purposes.

Type V is generally blue in colour and made entirely of cotton fibres. The density is not less than 1·15 gms. per c.c. The electric strength is greater than that of the other two and its ageing properties are superior. It is also more expensive, and on this account is only used in machines subject to high temperatures, such as traction motors.

Origin of the Fibres

Some knowledge of how these materials are manufactured will be of value. Jute fibres are obtained from an annual plant which grows in India. It is largely used for the manufacture of coarse cloth and sacking. The cotton is obtained in the form of cuttings produced in the shaping of garments to patterns. Thus all the cotton rags used are new. Both materials are first hand-sorted to ensure that foreign matter is eliminated, after which they are cut up into small pieces and boiled for several hours.

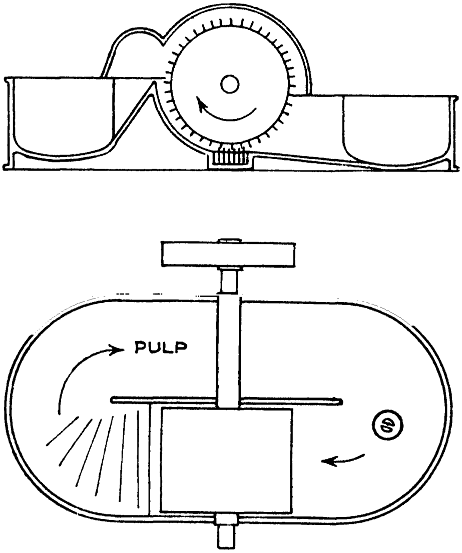

Fig. 9—Section and plan of a beater.

Beating the Raw Material.

The next process is known as beating, the purpose of which is to reduce the material to very fine fibres. Fig. 9 is a diagrammatic picture of a beater. The rotating cylinder has knives on its circumference and these carry the rags past other knives in the stationary part, the clearance between the two being very small so as to tear the material. Constant circulation is provided by the channel shown in the plan. It is essential that the fibres are reduced to a definite degree of fineness if the final product is to be of constant quality, and frequent checks of the pulp are taken. The beating process takes several hours and when complete the pulp is run into a large tank on the floor below, which is known as the stuff-chest.

A beater drum weighs many tons and takes about 100 H.P. for driving.

Water is added to the pulp in the stuff-chest so that the resulting mixture contains only about a half of one per cent of fibrous materials. It then passes through centrifugal extractors, in which any heavy particles are removed, and then passes on to the board making machine.

MAKING PRESSBOARD.

A diagram of a board making machine is depicted in Fig. 10. The three drums A, are in reality rotating screens, their perimeters consisting of fine mesh copper gauze. The liquid or stuff, as it is called, flows into the tank, through the gauze and out through the hollow spindles. The pulp is deposited on the outer peripheries of the drums.

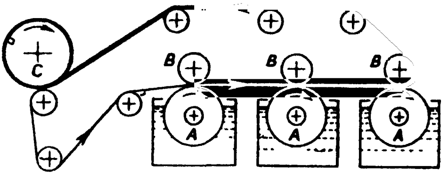

FIG. 10—Diagram of a board-making machine.

It is picked up on the underside of an endless woollen felt which passes over the three drums and is pressed into contact with the pulp by the so-called couch rolls B. An additional thickness of pulp is picked up from each drum and the three are carried by the felt to the making roll C, where the requisite thickness is wound on for making a finished sheet.

A knife is then run along the slot and the product peeled off as a soft board. The boards are stacked with heavy cotton sheets between them and hydraulically pressed, after which they are dried at a low heat for several hours, cut to size and calendered. A dried and calendered sheet is less than half the thickness of the sheet originally wound on the drum.

MANUFACTURING PRESSPAPER

In making presspaper, which is in continuous lengths, the pulp must be built up to the required thickness before it leaves the endless belt To do this more drums are used Fig 11 shows a multi-ply presspaper making machine in which eight drums are employed

FIG 11—Multi-ply presspaper-making machine
(B S & W Whiteley Ltd)

After leaving the endless belt the pulp passes through a number of squeezing rolls which remove a big proportion of the water It is then carried on an endless canvas belt which passes under and over a large number of heated rolls and is finally rolled up as dry presspaper Calendering to smooth out slight inequalities and increase the density is then carried out as a separate operation The amount of calendering is increased if a polished surface is required

It is of interest to note that no binder of any description is used. The material is held together solely by the interlocking of the fibres

TESTS FOR PRESSBOARDS AND PRESSPAPERS

Pressboards and Presspapers for electrical purposes have been manufactured in this country for more than a quarter of a century, and their never-failing high quality has rendered unnecessary all but occasional tests. In general a rough check of the thickness is all that need be done. If such materials are obtained from abroad more thorough checking may be desirable, in which case the following tests based upon BS. 231-1936, will be helpful.

A. FINISH.

Sheets or rolls should be uniformly and smoothly finished. The surface finish may be either plain or matt; or may be suitably glazed or planished as specified by the purchaser.

B. THICKNESS.

This is invariably measured in the "as received" condition. The average of a few micrometer measurements taken at random on sheets or rolls should be sufficient for checking material for normal duties. The mean thickness should not exceed the nominal, and the tolerance on thickness is—

Up to and including ¼ in. = −10 per cent.
Above ¼ in. = −25 mils.

In any one board above 20 mils thick, the thickness at any point should not differ from the mean thickness by more than ± 5 per cent. Variations in thickness are not given for thinner boards or papers, but a tolerance of ± 10 per cent is not unreasonable. If any material does not appear to conform to the foregoing and is unsuitable, the more precise methods given in BS. 231 should be tried before it is condemned.

C. DENSITY.

This is ascertained by weighing a suitable specimen after it has been dried at 80°C. (± 2°C.) for 18 hours. The density expressed in terms of weight in grammes per cubic centimetre is obtained by weighing a specimen 3 ins. in diameter, or 3 ins. square. The area of the specimen is computed in the case of a circle, from the mean of ten measurements of the diameter at equidistant points around half the circumference. In the case of the square ten measurements are taken at points equally spaced along each of two sides at right angles. The thickness is taken as the mean of ten readings, taken with a suitable micrometer at points equally spaced around the perimeter.

Material purporting to be a certain type of pressboard, shall comply with the figures given for the appropriate type earlier in this chapter.

D. ELECTRIC STRENGTH.

The figures given in BS. 231 - 1936 were obtained by tests in transformer oil at 90°C. It is doubtful whether such figures bear any relationship to what would be obtained by testing the material in air, the condition in which it works in machines.

Figs. 12 and 13 indicate what should be expected as minimum breakdown voltages when the specimens are tested in air after being subjected to all the following treatments:

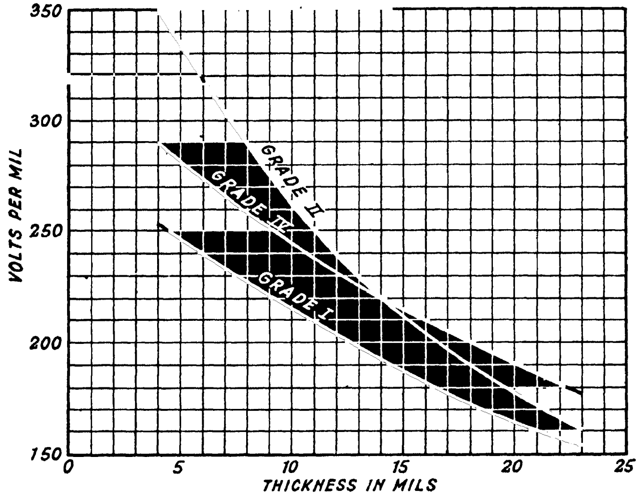

FIG. 12—Electric strength (Proof Test) of pressboard in air at 90 deg. C.

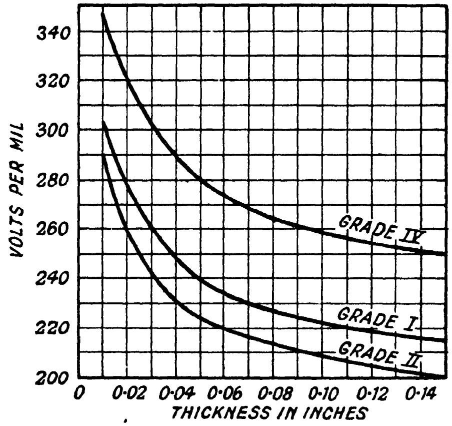

FIG. 13—Electric strength (Proof Test) of multi-ply presspapers in air at 90 deg. C.

Dried at 75°C. to 80°C. for 18 to 24 hours then—
Subjected for not less than 18 hours to an atmosphere of 75 per cent relative humidity (See Appendix B) at 15°C. to 25°C. and, finally—
Heated to between 90°C. and 95°C. and maintained at this temperature for 5 minutes before applying the voltage.

The tests were made in air between electrodes of the type described in Appendix D. The air and electrodes were at 90°C. to 95°C. during the application of the voltage.

When used in machines the material is generally coated with varnish, so that its electric strength should then be much greater than given in the curves. Since the electric strength would depend upon the quality of the varnish, and the thickness of coat, it is not possible to give figures that would have any real value.

E. FLEXIBILITY AND AGEING.

These are important properties especially for the thinner presspapers, since they are often used as backing material for micanite slot liners and heat may be employed in their fabrication. Unless these properties are good, the liners may crack when being bent to form troughs or when being folded over the tops of coils in slots, prior to wedges being fitted.

Before material is tested for these qualities, it is aged as described in Appendix B. Thin specimens are tested by folding, thicker ones by bending through an angle of 90 degrees round a rod of the appropriate diameter specified in Table 2. When making

Table 2.—Flexibility and Ageing of Presspaper and Pressboard.

Nominal Thickness inch	Miniumum Number of Folds or Diameter of Rod round which specimen can be bent, without fracture, in either longitudinal or transverse direction.	
	After Conditioning only.	After 48 Hours' Heating in Air at 150°C.
Type I Pressboard:		
Up to 0·02	2 folds	¾ inch.
$\frac{1}{32}$	1 fold	1¼ inches.
$\frac{1}{16}$	½ inch.	2½ inches.
$\frac{1}{8}$	1½ inches.	4½ inches.
Type II Pressboard:		
0·01	20 folds.	2 folds.
0·02	20 folds.	½ inch.
$\frac{1}{32}$	4 folds.	1 inch.
$\frac{1}{16}$	¼ inch.	2 inches.
$\frac{1}{8}$	1 inch.	3 inches.
$\frac{3}{16}$	1¾ inches.	4 inches.
$\frac{1}{4}$	2½ inches.	5 inches.
$\frac{3}{8}$	4 inches.	7 inches.
Type IV Pressboard:		
$\frac{1}{16}$	1 inch.	4 inches.
$\frac{1}{8}$	2 inches.	12 inches.
Type V Pressboard:		
0·010	20 folds.	2 folds.
0·015	20 folds.	1 fold.
0·020	20 folds.	⅛ inch.
$\frac{1}{32}$	20 folds.	½ inch.
$\frac{1}{16}$	20 folds.	¾ inch.

the folding test the specimen is first doubled flat on itself, after which it is re-folded on the same crease in the reverse direction. In other words, the material is bent through 360 degrees on the same crease. The original half bend is ignored, and the number of bends through 360 degrees before fracture are counted. Reasonable finger pressure is used after each fold.

Other specimens should be similarly tested after they have been heated at a temperature of 150°C. for 48 hours, and then conditioned in accordance with Appendix B. All tests should be made in both the longitudinal and transverse directions of the material.

F. Cohesion between Layers.

This test is made on conditioned specimens two inches square. If a split is started at one corner by the insertion of a knife, it shall not be possible to split the whole length of the sample parallel to the surface in the case of Types I and V. Type II should not split readily parallel to the surface.

G. Machining Tests.

All presspaper and pressboard shall be capable of being sheared, and material up to $\frac{1}{8}$ inch thick shall be capable of being punched also, without showing any signs of ragged edges.

H. Impregnation with Bituminous Compound.

A standardised test is given in BS. 231 which requires the use of Class III compound to BS. 688-1936. Specimens about 12 inches square are to be vacuum dried at 95°C. to 100°C. for four hours in a vacuum of not less than 25 inches and then impregnated in the compound at 150°C. for eight hours.

Strips approximately one inch wide are then to be cut from the specimen, both in the longitudinal and transverse directions, and bent round a rod of the appropriate diameter specified in Table 3 without showing any sign of cracking or splitting.

Table 3.—Bending Test after Impregnation of Presspaper and Pressboard.

Limits of Thicknesses. Inch.	Diameter of Rod. Inches.
Up to $\frac{1}{16}$ ...	$\frac{3}{4}$
Above $\frac{1}{16}$ up to $\frac{1}{8}$ ...	2
Above $\frac{1}{8}$ up to $\frac{3}{16}$ ...	3
Above $\frac{3}{16}$ up to $\frac{1}{4}$ ...	6

Since the user may not use Class III compound it may be better for tests to be made in the compound normally employed and under the conditions normally obtaining. It may be necessary to specify on the order the conditions which the material will have to meet.

J. FREEDOM FROM CONDUCTING PARTICLES.

This test is not applied to boards thicker than $\frac{1}{16}$ inch. The material shall be free from conducting particles when tested in the apparatus depicted in Fig. 14. Provided the material has been stored so as to obtain the condition of ordinary room humidity it need not be conditioned before this test which is made at normal room temperature. Specimens should not be less than 12 inches wide. They should be drawn at a speed of about 20 feet per minute between the overlapping rollers and plate. The rollers are of brass 1 inch long and $\frac{7}{8}$ inch dia, with edges rounded to a radius of $\frac{1}{32}$ inch.

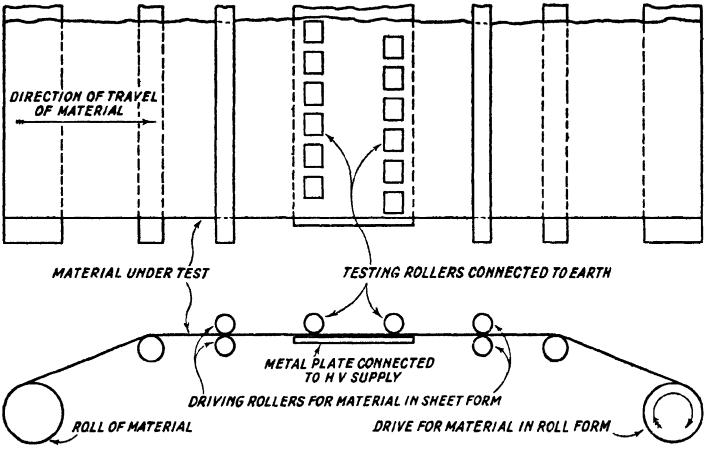
DIRECTION OF TRAVEL OF MATERIAL
MATERIAL UNDER TEST
TESTING ROLLERS CONNECTED TO EARTH
METAL PLATE CONNECTED TO H V SUPPLY
DRIVING ROLLERS FOR MATERIAL IN SHEET FORM
ROLL OF MATERIAL
DRIVE FOR MATERIAL IN ROLL FORM

FIG. 14—Apparatus for test for conducting particles.

The voltage applied between the rollers and plate should have a frequency of 50 cycles and be equivalent to 100 volts (RMS) per mil of thickness. A lamp or other suitable indicator should be used to demonstrate any failure of the material.

K. WATER CONTENT.

The amount of water in all types of presspapers and boards as received shall not exceed 8 per cent when ascertained thus: weigh a piece in this state about $1\frac{1}{2}$ inches square then heat in air at 105°C. (± 2°C.) until it reaches constant weight. The water content is the difference in weight. The percentage is computed on the dry weight of the specimen.

CHAPTER V

FIBRE AND LEATHEROID

Fibre is frequently known as vulcanised fibre, and leatheroid is variously called fishpaper or leather paper. Both are alike in composition, leatheroid being the name given to the thinner products.

These products are made very largely for other than electrical uses, and much of it is not suitable as insulation. It is, therefore, important to state on orders when the material is required for use as electrical insulation and to purchase only from firms which specialise in this quality.

MANUFACTURE OF FIBRE AND LEATHEROID.

Old cotton rags are used for this material. They are boiled, beaten, and the pulp deposited in board machines, in the manner described in the previous chapter. It is in the next operation that the major change is brought about. After leaving the felt belt the paper is passed through a bath of zinc chloride solution before being wound on to the drum for making into boards. When removed from the drum, the boards pass through a series of tanks, each containing a weaker solution of zinc chloride, until finally they are given a long washing in pure water to remove all traces of the salt. This is a very lengthy process, and may take as long as 10 to 12 months for boards 1 in. thick.

Material of paper thickness is made by a continuous process in which it passes slowly through a series of tubs and is finally dried. The effect of the zinc chloride is to convert the surface of the cotton pulp into a gelatinous mass of cellulose, the layers become coagulated and the laminated structure disappears. Zinc chloride is a very deliquescent salt, and unless all traces of it are removed the material will always tend to absorb water, in which case it is useless for electrical work.

SPECIFICATION FOR FIBRE.

British Standard No. 216-1936, Vulcanised Fibre (Natural Colour) for Electrical Purposes, covers fibre from $\frac{1}{16}$ in. to 1 inch in thickness. Since Fibre is seldom used in machines for any purpose except as wedges, only clauses covering such uses will be considered.

FINISH.

Sheets should be uniformly finished with a smooth matt surface, and be free from twisting, splitting along the edge and excessive warping. They should be supplied trimmed with square edges, unless otherwise specified, and be reasonably free from fractures.

TOLERANCE AND THICKNESS.

The thickness should not be less than the nominal thickness or exceed it by more than the tolerance in Table 4. The thickness is measured in the "as received" condition and is taken as the mean of a number of micrometer readings.

Table 4.—Tolerance on Thickness, Density and Shearing Strength of Vulcanised Fibre.

Nominal Thickness ins.	Tolerance Mils	Density g. per cm.^{3}	Minimum Shearing Strength, lbs./sq. in.	
			Longitudinal	Transverse
$\frac{1}{16}$	+ 9	1·20	14000	12000
Above $\frac{1}{16}$ up to $\frac{1}{8}$ incl.	+ 12	1·30	14000	12000
" $\frac{1}{8}$ " " $\frac{1}{4}$ "	+ 15	1·25	11000	9000
" $\frac{1}{4}$ " " $\frac{3}{8}$ "	+ 18	1·20	9000	8000
" $\frac{3}{8}$ " " $\frac{1}{2}$ "	+ 22	1·20	9000	8000
" $\frac{1}{2}$ " " $\frac{3}{4}$ "	+ 30	1·15		
" $\frac{3}{4}$ " " 1 "	+ 35	1·10		

DENSITY.

The minimum permissible density is given in Table 4. This is determined on a specimen about 1½ inches square. Weigh the specimen in air and also in an inert liquid of known specific gravity, e.g. petrol.

$$\text{Density} = \frac{W_1 x}{W_1 - W_2} \text{ grammes/cc.}$$

W_1 = weight in grammes of specimen in air.
W_2 = weight in grammes of specimen in inert liquid.
x = sp. gr. of inert liquid.

If checking a bulk consignment it may be better to measure and weigh sheets and avoid the loss of time in cutting off pieces.

MOISTURE LOSS AND SHRINKAGE IN AIR.

These should not exceed the figures given in Table 5.

Table 5.—Moisture Loss and Shrinkage of Fibre Sheets in Air.

Thickness of Sheet	Maximum Permissible Moisture Loss Per cent.	Maximum Permissible Shrinkage Per cent.		
		Longitudinal	Transverse	Perpendicular
All thicknesses ...	8	2	3	6

These are determined on a specimen 1½ ins. square cut from a position at least 1 inch from the edges of the sheets. The piece is weighed in the condition as received. It is measured after conditioning for 18 hours at 15°C. to 25°C. and 75 per cent (± 5 per cent) relative humidity (see Appendix B). The specimen is then heated in a well ventilated oven for 48 hours at 105°C. (± 2°C.), after which it is weighed and measured. The moisture loss is the difference in weights and the percentage is computed on the original weight.

Attention is drawn to the difference in computing the loss in this case and that of pressboard; in the latter the percentage water content is computed on the weight of the specimen after drying.

The percentage shrinkage is computed on the dimensions after conditioning.

WATER ABSORPTION

This should not exceed the value given by the curve in Fig. 15. A specimen 1½ ins. square is conditioned as described in Appendix B and then weighed. It is then immersed in distilled water at 20°C. (± 2°C.) for 24 hours. After removal from the water and wiping down it is re-weighed. The percentage absorption of water is computed on the weight of the specimen after conditioning.

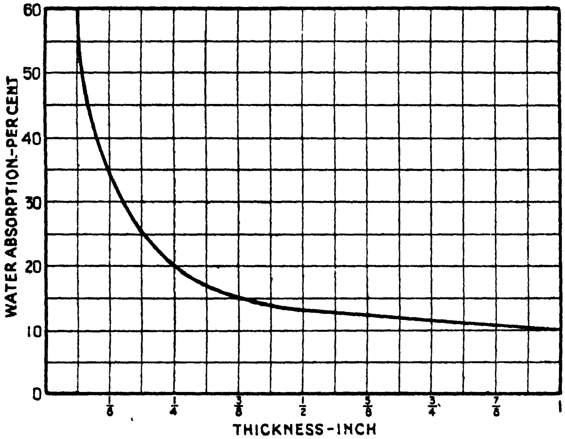

FIG. 15—Maximum permissible water absorption of vulcanised fibre sheet.

MACHINING TESTS.

Fibre of the type under discussion should stand shaping, milling, turning and drilling, and tapping with a No. O.B.A. tap without showing signs of splitting, cracking, chipping or raggedness.

SHEARING STRENGTH.

This should not be less than the appropriate value given in Table 4.

If the longitudinal and transverse directions are not known a specimen is cut with its length parallel to one side of a sheet, and one at right angles to this. The specimen having the greater value of shearing strength is deemed to have been cut from the longitudinal direction.

The specimens are cut out 3¾ in. long × ¾ in. wide (± 10 mils). Before making the test they are conditioned for not less than 18 hours at 75 per cent (± 5 per cent) relative humidity (Appendix B).

A drawing of the apparatus for this test is given in Fig. 16; the punch should be a running fit in the die. A steadily increasing load is applied at such a rate that the specimen is sheared in about two minutes.

The shear stress is computed from :—

$$S = \frac{W}{2\ BTK.}$$

where S = shear stress in lbs./ins.^{2}
W = shearing load in lbs.
B = width of specimen in inches.
T = thickness of specimen in inches.
K = coefficient (= 1.016) to allow for curvature of sheared surface.

FREEDOM FROM CHLORIDES.

The total amount of chlorides calculated as chlorine should not exceed 0.1 per cent computed on the original weight of the specimen. It was pointed out early in this chapter how important it is that the material should be free from zinc chloride.

TREATMENT OF FIBRE FOR WEDGES.

It is clear from the foregoing that special precautions are necessary when making fibre wedges to avoid swelling or shrinkage. They should be sawn out roughly to size and dried at 85°C. for about 24 hours and then machined immediately on removal from the oven. As soon as possible after machining they should be again dried out for an hour, immersed in thin insulating varnish and baked until dry.

Different consignments of fibre behave differently and the times just given may have to be varied. It is usual to take a specimen

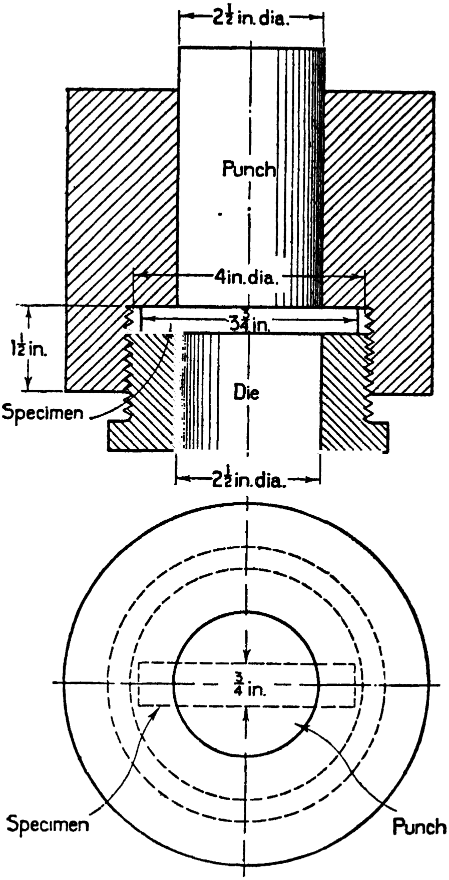

Fig. 16—Punch and die for shearing strength test of vulcanised fibre.

out of the stove at intervals and bend it by hand to ascertain whether it is becoming too brittle. Fibre should not be dried so that it will readily snap when bent between the fingers.

Leatheroid.

There is no British Standard but the following data is reliable and may be used as the basis for a purchasing specification.

Finish.

The material should be heavily calendered so as to produce a uniform and smooth surface.

Thickness.

Should not be less than nominal thickness nor exceed it by more than the tolerance in Table 6.

Table 6.—Tolerance on Thickness, Density and Ageing Figures for Leatheroid.

Nominal Thickness	Tolerance	Density	Ageing Tests. Diameter of Mandrel. ins.	
Mils	Mils	g. per cm.^{3}	Longitudinal	Transverse
5	+ 1	1·10	$\frac{1}{8}$	$\frac{1}{8}$
10	+ 2	1·10	$\frac{1}{5}$	$\frac{1}{8}$
15	+ 3	1·15	$\frac{3}{16}$	$\frac{3}{8}$
20	+ 4	1·20	$\frac{1}{4}$	$\frac{1}{2}$
25	+ 5	1·25	$\frac{1}{4}$	$\frac{1}{2}$

DENSITY.

Not less than that given in Table 6.

ELECTRIC STRENGTH.

This test is made in the condition as received; two tests are applied on samples taken from any sheet—

(*a*) When tested with the electrodes described in Appendix D the material should withstand for 1 minute, without breakdown and without sign of steaming or smoking, a voltage equivalent to 120 volts/mil of nominal thickness.

(*b*) When the sample is folded flat on itself and creased, then opened out, it should withstand for 1 minute 60 volts/mil at the crease, using the same electrodes.

RESISTANCE TO SURFACE BREAKDOWN IN AIR.

The leatheroid should stand the following test without flashover or injury.

A potential difference of 16 kV applied for 1 minute between two 1½ ins. diameter electrodes placed on end and spaced 1 inch apart.

TENSILE STRENGTH.

Of any material up to and including 25 mils, not less than 8000 lb./sq. in. in the longitudinal direction, and not less than 5500 lbs./sq. ins. in the transverse direction.

RESISTANCE TO AGEING.

One inch wide strips cut out in both the longitudinal and transverse directions should be aged at 105°C. (± 2°C.) for 48 hours after which they should stand bending, without fracture or cracking, through 90 degrees around a mandrel of the appropriate diameter given in Table 6.

FREEDOM FROM CONDUCTING PARTICLES.

This test should be carried out with the apparatus shown in Fig. 14 and in the manner described in the previous chapter, using a voltage of 100 volts per mil of nominal thickness.

PRESENCE OF CHLORIDES.

These should not exceed 0.1 per cent when calculated as chlorine and computed on the original weight of the specimen.

COMPARISON OF LEATHEROID WITH PRESSPAPER.

Leatheroid is hard and smooth whereas presspaper has a softer surface which, although smooth at first, quickly becomes rough when subject to abrasion. For example, if armatures are wound by rotating them on a faceplate as shown in Fig. 82 (p. 192) the wire is led into the slots by sliding down the slot liners, which protrude through the slot openings for the purpose. If the protruding liners are of presspaper the wire quickly causes the surfaces to become rough, in which condition they may abrade the covering on the wire. If they were of leatheroid the surfaces would remain smooth.

In small armatures and stators wedges of 20 mil leatheroid are often used. Presspaper is unsuitable because it is not stiff enough to enable wedges of it to be pushed into slots that are well filled with wire.

There are many other cases where mechanical stiffness and smoothness are desirable, and for which leatheroid is preferable. Presspaper remains flexible under heat much better than leatheroid, and for this reason is generally used for slot leading-in liners when formed coils are employed.

Owing to its greater flexibility presspaper is often used for the insulation between layers of windings, *e.g.*, in the end windings of armatures.

Similar differences exist between fibre and pressboard. It would not be possible to use pressboard wedges in large machines, where the thickness is perhaps $\frac{3}{16}$ in. or $\frac{1}{4}$ in.

For field spools, especially if the coils are wound on the spools and have to be impregnated, pressboard is preferable. It will remain pliable whereas fibre may become brittle and easily snap off at corners.

CHAPTER VI

PAPERS FOR ELECTRICAL PURPOSES

Although papers do not enter into the insulation of small machines, they are of great importance in the insulation of larger machines in which mica is the prime insulator. It is, therefore, appropriate that they should be considered. It is important that the number of papers required can be reduced to two or three as it is often difficult at the present time, and has been for some years, to obtain the right quality of one of them, viz., the chemical wood-pulp type. The two types are tissue paper and chemical wood-pulp paper.

JAPANESE TISSUE PAPER.

Before and during the early part of the war, the tissue used was Japanese, made from a native plant. The fibres were long and were aligned in such a manner that the paper had great strength in the machine or longitudinal direction but was very weak in the transverse direction.

Weakness in the transverse direction was not of importance since care could always be taken to cut the paper in such a manner that if tension were used in its application it was applied in the longitudinal direction. Unfortunately, consignments varied and at times paper was received which was too weak for certain operations. The thickness averaged 1 mil. It was very absorbent to varnish, an ideal characteristic for built-up insulations.

SUPER FLEXROPE PAPER.

About 1941 a new paper known by the above name was introduced into this country from the United States to take the place of Japanese tissue. In appearance and properties it is very much like Japanese tissue. It is strong in the longitudinal direction and weak in the transverse direction. It is made in thicknesses of 0.85 and 1 mil, and is very absorbent to varnish.

This paper is made from old manila ropes. These are cut into lengths of about 3 ins., cleaned, boiled and beaten in the manner described for pressboard manufacture. The surprising feature of the whole process is that the paper is made by depositing the pulp on gauze cylinders and picking it off by an endless belt in the manner illustrated in chapter IV. As a rule, paper is made from pulp deposited on a gauze belt, of which details are given in the next section.

It may be recorded that 1 mil thick paper has proved to be an ideal substitute for Japanese tissue. Data are given in Table 7.

CHEMICAL WOOD-PULP PAPER.

A chemical wood-pulp paper is the other paper of importance. The thinnest obtainable consistent with the strength required, is about 1½ mils. During recent years, electrical manufacturers have not been able to choose their source of supply, and considerable trouble has resulted from the varying densities and different amounts of calendering that have been given. Difficulty has arisen at times in making mica splittings adhere to the calendered surfaces, which are largely non-absorbent of varnish. The pulp for these papers is generally made near the forests from which the timber is obtained. The wood is cut by machinery into small pieces which are then digested with suitable chemicals, such as calcium bisulphite, or sodium sulphate, dissolved in water. The process is carried out under steam pressure at 40 lbs. or more, the time required varying from 48 hours to as little as 9 hours if higher pressures are employed. The chemicals remove the resin and lignins, leaving only the pure cellulose fibres. These are thoroughly washed and the pulp is then made up into boards (as described in chapter IV) for shipment to the paper mills. At the paper mills the pulp is broken down, mixed with water and well beaten so as to reduce the fibres to a size suitable for making a definite type of paper. The importance attached to beating will be appreciated when it is realised that the difference between blotting paper and greaseproof paper is entirely due to the amount of beating. After beating, the pulp goes to the stuff chest where water is added so that the " stuff " which is run on to the paper-making machine contains only about 0.5 per cent of solids.

In paper making, only one layer of pulp is deposited and the use of several drums for collecting the pulp is unnecessary. The stuff is run on to an endless belt of fine copper gauze which is several yards in length. The water flows away through the gauze and leaves the pulp behind. To aid the felting or interlacing of the fibres, the whole length of gauze belt is made to oscillate sideways, for about ½ in. 2 or 3 times per second. Suction is applied under the belt near the far end for the purpose of removing as much moisture as possible. The paper is then strong enough to be led from the wire belt, usually known as the couch section, on to the press section where it is carried on a woollen felt and squeezed between pairs of rolls. This reduces the water content to about 70 per cent. This is the lowest figure possible with mechanical pressure. The remaining water is removed by passing the paper over numerous heated rolls after which it passes through a calender and is rolled up. If heavy calendering is required it is carried out as a separate operation.

Tests for Papers.

Tests for papers are covered by BS. 698-1936, Papers (Unvarnished) for Electrical Purposes. With the exception of Japanese tissue, none of the papers for which data are given are suitable for the manufacture of machine insulation.

Papers for backing mica and similar purposes should be absorbent and not more than 2 mils thick; the thinnest for which figures are given is 3 mils.

However, the tests given in BS. 698 are useful for enabling figures to be taken on papers not covered by this specification. Data for some such papers are given in Table 7.

Conditioning Samples.

Before making tests the papers should be conditioned at 15°C. to 25°C. for not less than 18 hours, in a controlled atmosphere of 65 per cent relative humidity. See Appendix A.

Measurement of Thickness.

The thickness is determined by measuring ten pieces together and taking the mean. The tolerances permitted are given in Table 7. A ratchet micrometer having an anvil and spindle diameter of not less than $\frac{3}{8}$ in. or more than $\frac{1}{2}$ in. is employed.

Substance.

The substance of the paper is the weight in grammes per metre^2. Several samples should be taken. Heavy substance provides relatively good mechanical and electrical properties but generally means poorer absorption characteristics. In this respect, judgement has to be used because good absorption is necessary if varnish and mica splittings are to adhere well, at the same time a fair amount of mechanical strength is required for wrapping purposes.

Ascertaining the Longitudinal and Transverse Directions.

For some of the tests it is necessary to know the longitudinal and transverse directions of the paper. If this is not evident due to the smallness of the sheet, it can be ascertained as follows. Cut two strips of paper about 6 ins. long and 1 in. wide; one is to be cut with its length parallel to one edge of the sheet, and the other strip in a direction at right angles. Place the two strips one above the other, and hold them horizontally by one end. The strip which bends least has been cut in the machine or longitudinal direction of the paper. If both strips bend equally turn them upside down.

Table 7.—Data for Papers.

	Japanese Tissue		Super Flexrope		Sulphate Wood Pulp		Sulphite Wood Pulp	
Nominal thickness	1 mil		1 mil		1·5 mil		2 mil	
Tolerance on thickness ..	± 20 per cent.		± 10 per cent.		± 11 per cent.		± 10 per cent.	
Substance : Grms/M^2 ..	10		16		38		33	
Tolerance on substance ..	—		—		± 5 per cent.		± 5 per cent.	
Bursting strength Max. permissible decrease	40 per cent.		—		20 per cent.		15 per cent.	
	Mach.	Across	Mach.	Across	Mach.	Across	Mach.	Across
Tensile lbs./ins. width ..	5-9	1·5-3	7·5 -11	0·75-1·1	13·5-16·7	5·5-6·5	11	7
Tensile after ageing * ..	—	—	4.6 - 8	0·58-0·75	14 -14·8	5·3-6·2	—	—
Tearing E.R.A. ounces ..	0·5-1	1·5-2·5	—	—	—	—	—	—
Tearing Marx. Elmendorf. Grms. ..	8-18	15-30	46-51	—	44-52	60-68	24	27·5
Tearing Marx. Elmendorf after ageing*	—		24-36	—	21-36	26-50		
Oil Absorption ins.	—	—	1·25-3·25	0·9 -1·5	1-1·25	0·75	1·5	1·25

* The ageing was different from that employed for the "Bursting Strength Test." These specimens were aged for 24 hours at 110°C. followed by conditioning for 18 hours at 15-20°C. in 65 per cent. relative humidity.

TENSILE STRENGTH.

Tensile strength should be checked in both directions on conditioned specimens. The clear length of the specimens between jaws should not be less than 6 in. or more than 8 in. and the width of the specimen between ½ in. and 1 in. The results are to be computed in pounds per inch width.

Figure 17 depicts a simple apparatus for making the test. A bracket is bolted to a bench and suspended from it is a jaw consisting of two pieces of steel, the grip being obtained by tightening the two bolts. A thin piece of rubber attached to the inner faces of the two clamps will ensure an even distribution of the grip. A can is suspended from the lower grip. Fixed to the upper part of the bracket is another canister having a conical inside base—shown dotted. This cannister is filled with small lead shot which is permitted to run into the lower can by operating the pivotted disc valve. The flow is stopped immediately the specimen breaks.

The breaking load is found by weighing the can with its contents and grip. The load should be applied at approximately 2 lbs. per second per inch of width. Specimens which break at the grip should be neglected.

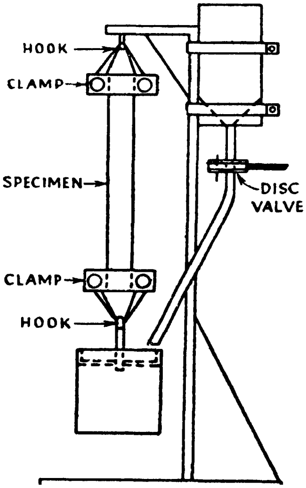

FIG. 17—Apparatus for tensile tests of papers and tapes.

TEARING STRENGTH.

Resistance to tearing is an important test. Two methods are described in BS. 698. One is known as the E.R.A. (Electrical

Research Association) double tear and other as the Marx-Elmendorf double tear. The latter method is used for all investigational work and for routine work by firms which possess the special testing apparatus.

The E.R.A. apparatus can be made up by anybody who wishes to make occasional tests and will, therefore be described. It is illustrated in Fig, 18. The two holes in the specimen must be punched and have perfectly clean edges. The tongue for attaching to the clip is made by cutting along the dotted lines. Ten tests are taken in each direction and the mean of each is deemed the tearing strength in the machine and transverse directions respectively.

It should be noted that the tearing strength is generally greatest in the transverse direction.

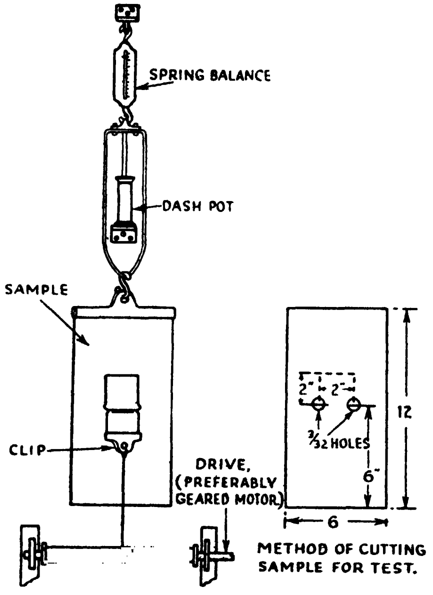
SPRING BALANCE
DASH POT
SAMPLE
CLIP
DRIVE, (PREFERABLY GEARED MOTOR)
2"
2"
3/32 HOLES
12
6"
6
METHOD OF CUTTING SAMPLE FOR TEST.

Fig. 18—Apparatus for tearing strength of papers.

Ageing.

The determination of the ageing properties of a paper is of great importance, since it may be used in machines which run for years at elevated temperatures, e.g., in generators in power stations.

The test is made by clamping the specimen on to a ring not exceeding 1¼ ins. dia. and applying air pressure until it bursts. The arrangement is shown in Fig. 19.

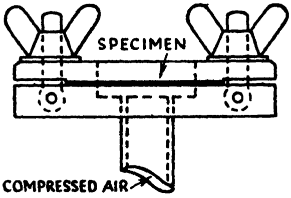

FIG. 19—Apparatus for ageing test of papers.

The bursting strength before and after ageing is determined on the same sample, alternative positions being used on the one piece in two series of tests. For the un-aged tests the samples are conditioned as already described; after one burst they are suspended in an oven at 150°C. (± 3°C.). Papers of the tissue type are kept at this temperature for 24 hours, and those of the wood pulp type for 48 hours, after which they are again conditioned at the lower temperature before applying the bursting test.

Ten tests are made, five with one side of the paper uppermost and five with the other side uppermost, both before and after ageing. The mean value of the ten tests in each case is deemed the bursting strength.

The determining figure is the decrease in the bursting strength computed as a percentage on the original mean value.

Good ageing depends on freedom from acid or alkali so that, in general, there is no need to carry out the tests of a chemical nature described in BS. 698, if the paper ages well.

OTHER FORMS OF AGEING TEST.

Whilst the bursting strength test just described is useful in most cases, there are occasions when additions to some of the other tests may be more satisfactory. For example, when applying mica-paper to the slot portion of a turbo-alternator stator coil it is used in such a manner that the tension while wrapping it on operates in the transverse direction of the paper. Furthermore, heat is used in the process.

Tensile and double-tear tests after ageing may indicate the suitability of a paper for this purpose better than the bursting strength test. Figures obtained by such tests are given in Table 7.

OIL ABSORPTION.

The last test to be described enables some comparison to be made of the propensity of alleged similar papers for absorbing varnish. It is known as the oil absorption test.

There is another test, the measurement of the rate of flow of air through papers, which might be used for the same purpose, but it is not so simple to carry out. Furthermore the results of the air flow test may be vitiated by thin places in the paper. Thin places may not be of serious importance in papers used as carriers for mica, but the interpretation of air flow figures on such papers would give an entirely misleading indication of their general ability to take up varnish for providing good bonding.

The oil absorption is determined by suspending strips of paper 8 × 2 ins. in the manner shown in Fig. 20 three strips being cut from the longitudinal and three from the transverse direction. The strips are cut in pairs, one pair from each edge and one pair from the centre of the roll or sheet. A line is marked across each specimen exactly $\frac{1}{2}$ in. from the lower end and the specimens are pinned so that they hang vertically with their top edge level with the top of the bar. Small lead clips are attached to the lower end of each strip.

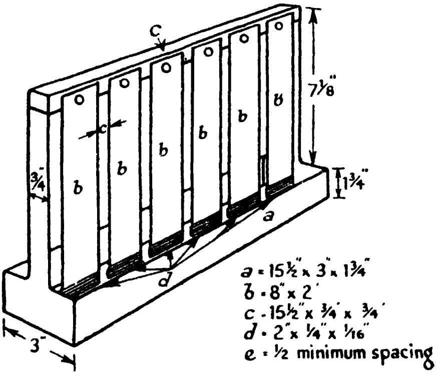

FIG. 20—Apparatus for oil-absorption test on papers.

The loaded apparatus is placed in an oven with a quantity of transformer oil complying with BS. 148 (any class) in a separate vessel. The oven is maintained at a temperature of 95°C. to 100°C. throughout the whole test.

After the lapse of not less than one hour sufficient oil is carefully transferred from the vessel to the tank by means of a funnel so that the surface of the oil is coincident with the lines marked on the specimens. The apparatus is left in the oven for a further two hours when the height to which the oil has risen in each specimen is noted.

Several other tests are described in BS. 698. They are useful when full investigations are required, but not generally carried out in routine testing.

CHAPTER VII

COTTON AND ITS PRODUCTS

PREPARATION.

Cotton is the seed hairs of the cotton plant. The raw material goes through several processes before it is fit for weaving. In the form in which it is used for weaving it is known as yarn, and it is from this state that it becomes of more immediate interest to those in the electrical industry.

TERMINOLOGY IN THE COTTON WEAVING INDUSTRY.

There are some terms used in connection with tapes and cloths which are imperfectly understood by electrical engineers. Thus a length of tape may be described as having a warp of 44 ends of 60/2s Egyptian yarn and a weft of 44 picks of 32s single Egyptian yarn. Definitions of these terms will be useful.

COUNT. The figures 60 and 32 are known as the " count " of the yarn. As the yarn is soft and readily compressible it is not practicable to measure or define its size or diameter in the usual manner. The most convenient way is to define some relationship between length and weight. The yarn is wound into hanks of 840 yards and the number of these hanks to make a weight of 1 lb. is known as the " count " of the yarn. Thus a 60s yarn is of such a size that 60 hanks, each of 840 yards are required to make up one pound weight. It follows that the greater the number of the " count " the thinner is the yarn.

TWOFOLD. Often two yarns are twisted together to form one thread. A thread of this nature is indicated by /2s after the count number. Thus 60/2s would be described as a twofold 60s yarn.

WARP. The warp is the lengthwise direction of the material and the threads running in that direction are known as the warp threads.

ENDS. If the end of a length of tape or cloth be examined it will be found that there is a large number of thread ends, as shown in Fig. 21. The weave is defined by stating how many of these " ends " there are per inch of width.

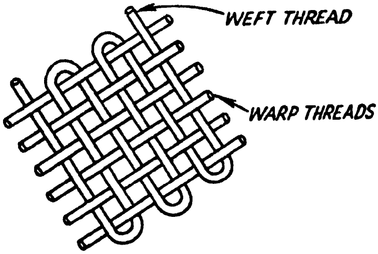

FIG. 21—Names of threads used in woven tapes and fabrics.

WEFT. The weft is the width of the material and the threads going across it are known as the weft threads.

PICKS. In the type of weaving employed for the tapes and fabrics under consideration the weft thread is continuous, as shown in Fig. 21. Consequently, there are no ends, and it is customary to count the number of weft threads per inch by picking them out with a pin. This, however, is not the origin of the term. The arm which knocks the shuttle to-and-fro between the threads is known as a "picker," and the term "picks" really refers to the number of strokes the pickers make when weaving one inch of material.

PLAIN WEAVING.

The principle of plain weaving may be understood by reference to Fig. 22. The warp threads are guided by passing through healds. These may be composed of thin steel wire bent as shown, or of string which has been rendered stiff by varnish or gum and opened out in the centre.

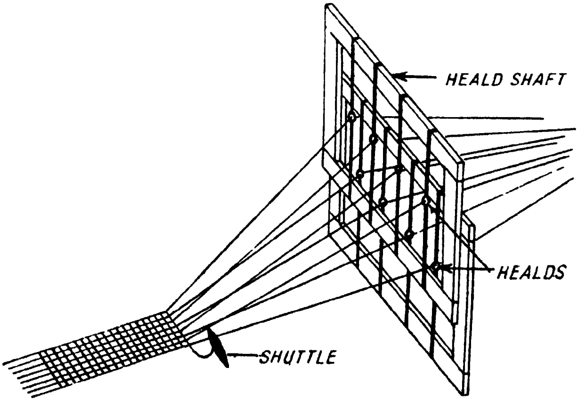

FIG. 22—Diagrammatic view of tape-weaving loom.

The healds are attached to wooden cross pieces known as heald shafts which are kept apart by uprights at the ends thus forming a structure like a picture frame One frame is fixed behind the other and the arrangement is such that the eyes in one set of healds are intermediate between those of the other set

When the shuttle has passed to the side of the tape opposite to where it is shown in the sketch, the upper frame is lowered and the lower frame is raised, so that the position of the warp threads is reversed The shuttle is then returned to its original position, and so the operation continues A reed mechanism is also necessary for pushing the weft thread up to the one already in position, after each pass of the shuttle This is not shown in the sketch

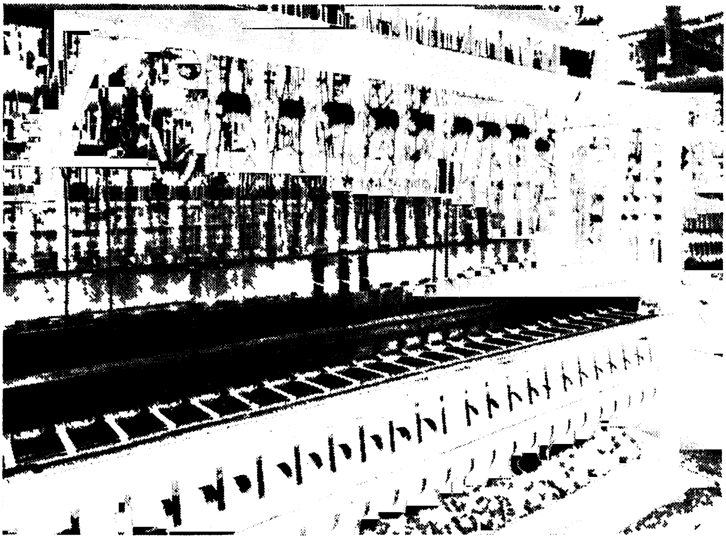

FIG 23—Weaving ¾in fine tape (James North Hardy & Son Ltd)

Figure 23 is reproduced from a photograph of a bank of looms weaving ¾ in fine tapes The shuttles are seen ready to enter between the warps A heald shaft is visible above the beam carrying the shuttle mechanisms

COTTON TAPES AND WEBBING

Data on tapes and webbings are given in BS 633-1935, Cotton Tapes and Webbing for Electrical purposes In what follows the word ‘ webbing ” will not be repeated; readers will have no difficulty in knowing when the text refers also to webbing It should be stated that this specification is not rigidly adhered to for the reason that many tape manufacturers have their own combinations of ends and picks which produce tapes that are equally serviceable.

The main essentials of tapes may be summarised briefly as follows:—

(*a*) The weave should be reasonably close so that when a taped coil is dried out and dipped in a good bodied varnish it will fill the interstices and form a seal. On the other hand it should not be too close or penetration by varnish may be difficult.

(*b*) The thickness should be within close limits. This is most important when taped strip is being employed for armature coils. There may be, for example, four strips side by side, and if the tape were say .001 in. over size, the total increase in thickness of the four strips together would be .016 in., assuming the tape is applied with a lap which is less than a half-lap. A coil so much over size in width would not enter a slot which had been designed for the correct thickness of tape.

(*c*) The tensile strength must be enough to enable normal taping operations to be performed without breakage.

(*d*) They must not contain any deleterious matter or chemicals. Electrical tapes are free from these faults. Their presence can be detected by determining the conductivity or resistivity of an aqueous extract.

(*e*) All classes should be wound tightly on a hard core. This generally consists of a cardboard tube of the same length as the width of the tape or webbing and having a hole through the centre of $\frac{3}{8}$ in. or $\frac{1}{2}$ in. diameter. The tape should be wound uniformly and sufficiently tightly so that when a roll is dropped to the floor the core does not fall out.

(*f*) Pins must not be used for fastening the ends of a roll, or for joining lengths together. There is no reason why most rolls of tape should not be free from joints, and the number permitted should be small, not more than say two in an occasional roll. If the tape is applied to coils by machine the presence of a stitched joint may cause "snatching" when passing over the machine guide. It is therefore safer not to have joints anchored in any way, merely have a new end interleaved in between the last two turns of the preceeding length.

(*g*) The maximum diameter of rolls should not be too great for ease in handling when taping, or for use in taping machines.

(*h*) It is an advantage to have a coloured thread down the centre, *e.g.*, a red coloured thread for fine tape and a blue one for ordinary tape. The benefits of having a line are described in Chapter XXI.

(*j*) It is specified in the British Standard that fine and ordinary tapes should be calendered, and if required, gassed and scoured, i.e., singed and washed. In general, however, ordinary tape is not gassed or scoured and none of these three operations is carried out on webbings. The adequacy of the gassing is ascertained by visual inspection. Experience is the only guide in this matter.

CLASSIFICATION OF TAPES.

In BS. 633 five classes of tape are defined; these are :—

Superfine tape is 3½ mils thick, and being very expensive is only used where room cannot be found for the other types.

Fine tape is often known as Egyptian cotton tape. It averages 5 to 6 mils in thickness and is generally employed for taping coils which have to go into confined spaces such as armature or stator slots.

Ordinary tape is variously known as Indian or American cotton tape. Indian cotton was used for these tapes many years ago, and the name still persists, although American cotton is now always used. The usual thickness is 7 to 8 mils. It is cheaper than the other two and is generally employed for taping where space is not confined, e.g., the end windings of stator coils, field coils, etc.

Webbing and Heavy webbing tapes are used mostly for binding purposes in big machines. The weave of these is known as twill weave and has the appearance of a V pattern, whereas the previous three types have a plain weave of the type illustrated in Fig. 21.

WIDTHS OF TAPES.

Tapes may be obtained in widths varying by ⅛ in. from ¼ in. up to 1 in., also 1¼ in., 1½ in. and 2 in. wide. All these widths are available in fine tape but the full range is not obtainable in the other types. The most popular widths are :—superfine ¼ in., ⅜ in. and ½ in., fine ½ in., ⅝ in., ¾ in. and 1 in., ordinary ¾ in. and 1 in., webbing ¾ in., 1 in. and 1¼ in.

STRIPPING OR SACRIFICE TAPE.

It is sometimes desirable to tape coils for a temporary period; e.g., coils to be impregnated in certain kinds of bitumen are covered with temporary tape which is removed and scrapped after the impregnation. A cheap type of tape, known as stripping or sacrifice tape is made for this purpose. It has an open weave down the middle, and a close weave at the edges to give the necessary strength.

A short specification for such tape would be:—

Thickness—7-8 mils.
Tensile—not less than 35 lbs./inch width.
Warp threads—not less than 8 threads in a band ⅛ in. wide along each edge and between 30 and 34 threads per inch in the open weave down the middle.
Weft threads—not less than 28 per inch.
Width—1 in., 1½ ins. and 2 ins.
Length—36 yards per roll.

DATA FOR TAPES.

A summary of the principle data is given in Table 8. All the figures excepting those for superfine tape are taken from BS. 633. This British Standard gives only details of thickness for superfine tape; all other data are from other sources.

Table 8.—Data for Cotton Tapes and Webbing.

	SUPERFINE	FINE	ORDINARY	WEBBING	HEAVY WEBB
Type of Cotton ..	Warp—Egyptian Weft—Sea Island	Egyptian	American	American	American
Count—Warp ..	2 Fold 100's	2 Fold 60's	2 Fold 28's	2 Fold 28's	2 Fold 20's
Count—Weft ..	2 Fold 140's	Single 32's	Single 24's	Single 20's	2 Fold 28's
Ends* ..	†	69W + 10	54W + 10	94W	100W
Picks per inch ..	†	42	30	44	40
Standard Thickness —Mils ..	3·5	6	8	15	23
Range of Thickness which may be specified—Mils. ..	3-4	5-7	7-10		
Tolerance—Mils ..	±0·5	±1	±1	±2	±3

* W is width of tape in inches or fractions.
† Details of one manufacture of superfine tapes are given below:—

Width ..	5/16″	⅜″	½″	¾″
Ends ..	29	41	55	83
Picks ..	48	44	44	44

THICKNESS.

The standard thicknesses and tolerances are given in Table 9. The purchaser may specify any thickness of tape within the limits given in column 3. The thickness is measured on a single layer with a ratchet micrometer, the diameter of the anvil and spindle of which is not less than ⅜ in. or more than ½ in. In tightening up the micrometer the ratchet must be employed. The micrometer spindle is to be closed on to the tape at the rate of about 2 mils per second, and the closing motion continued until the ratchet has clicked three times. This method of measurement is liable to give variable results, but is the only method recognised at present. The thickness is taken as the mean of a number of readings over and between the selvidges.

Table 9.—Thickness of Tapes and Webbings.

1	2	3	4
Class of Tape (Webbing).	Standard Thickness.	Range of Thickness which may be specified.	Tolerance Plus or Minus.
	mils	mils	mils
Superfine ...	3½	3 to 4	½
Fine	6	5 to 7	1
Ordinary ...	8	7 to 10	1
Webbing ...	15	—	2
Heavy Webbing	23	—	3

TENSILE STRENGTH IN WARP DIRECTION.

A convenient apparatus for testing tapes up to 1 inch wide is that illustrated in Fig. 17 and used for the testing of papers. Wider tapes, and all webbings, require a suitable tensile testing machine. When making these tests there should be at least 6 ins. of unstretched tape between the jaws of the machine. The mean value of five breaking loads is taken as the breaking load. Uneven breaks or breaks in or at the jaw are not to be taken into account. Minimum breaking loads are given in Table 10.

Table 10.—Tensile Strength of Tape (Webbing) (Scoured or Unscoured).

Width.	Minimum Breaking Load, pounds.			
	Fine.	Ordinary.	Webbing.	Heavy Webbing.
in.				
¼	17	—	—	—
⅜	20	—	—	—
½	23	32	—	—
⅝	26½	37	—	—
¾	30	42	70	—
⅞	33	48	—	—
1	36	53	88	—
1¼	—	63	110	150
1½	—	74	126	165
2	—	—	164	200

WIDTH.

This is measured by means of a steel rule, the tape being laid flat on a smooth surface. A tolerance of ± 6 per cent is permissible for all tapes and webbings.

LENGTH.

When measuring the length in a roll of tape it should be under a tension equal to the standard weight of 12 yards of the tape under test.

CONDITIONING OF SPECIMENS.

In general all the tests just described are carried out at room temperature and without any special conditioning. If, however, some of the figures are questionable the specimens should be conditioned as described in Appendix A before being tested.

DELETERIOUS SUBSTANCES.

Tapes made for the electrical industry by reputable firms are free from foreign substances. If doubt arises, the tape should be tested as described in Appendix E which covers the test for conductivity (resistivity) of aqueous extract. No indication of the maximum permissible conductivity is given in BS. 633, the onus of deciding this is placed upon the purchaser, who generally compares figures for new tapes with those for previous tests.

COTTON FABRICS.

Four general types of cotton fabric are in use. None of them is covered by British Standards. They are purchased in the open market without specifications, unless the purchaser draws them up for his own protection. In such cases the specifications are merely records of fabrics already purchased and their use helps to standardise the products.

GREY EGYPTIAN CLOTH 3-4 MILS.

This is a useful cloth for the manufacture of cloth-mica-paper, used for the overall taping of field and interpole coils, and in other places where the more expensive rayon or silk-mica tape need not be used.

A general make-up would comprise 80 ends and 71 picks per inch, both warp and weft being of 62s single combed Egyptian cotton.

SIZED CALICO.

Useful for protecting insulation applied to the coil supports and other metal parts of small machines.

A brief specification would be—a white, sized, cotton cloth having a plain weave. Thickness 4 to 5 mils; not less than 70 threads/in., warp, and about 60 threads/in. weft.

DUCK CLOTH.

This is used for protecting the insulation applied to the coil supports of large armatures and rotors, also for shrouds over the end windings of armatures subject to duty in very dirty places.

It is made of American cotton and is about 20 mils thick. The weave may be 48 ends and 44 picks.

SAIL CLOTH.

The chief use of this cloth is under the bandings of large armatures and motors. The average thickness is 25 mils. A typical specimen has 48 ends and 34 picks.

CHAPTER VIII

SILK AND RAYON FABRICS AND TAPES

Silk, and more recently rayon fabrics are used in great quantities. Their chief use is as a backing for mica tape where thinness is of importance, and where paper is not considered suitable for the purpose.

SIZE OF SILK AND RAYON YARN.

The unit for this purpose is not the count as used for cotton. It is the "denier" and is the weight in grammes of 9000 metres of the yarn. Thus the larger the thread used for a certain weave the greater the denier; in the case of cotton it will be remembered that the larger the thread the smaller the count.

SILK FABRIC.

Silk is one of the oldest articles of commerce. The Chinese claim to have started the weaving of silk more than 4000 years ago. The silk used in the electrical industry comes from Japan, which country has specialised in the very thin fabric needed for backing mica.

In Japan the industry is thoroughly commercialised. The silkworm eggs are incubated, the caterpillars are confined in cases and fed with mulberry leaves. Provision, in the form of layers of dried straw or grass is made for the silkworms to spin their cocoon, an occupation which takes about a week. The silk thread is a double filament produced by the hardening of a viscid liquid which exudes from two spinnerets in the head, the threads being cemented together by a glue emitted by two other glands. The unbroken length of twin filament obtainable from a single cocoon varies from 400 to 1,300 yards. Between forty and fifty cocoons are needed to make one square yard of the very thin silk cloth used for mica tape.

The quality of Japanese silk is known as 3 momme Habutai. "Momme" is a Japanese weight equal to about 0.13 ozs. "Habutai" is the name given to these light silks just as calico, for example, is a particular class of cotton goods.

As would be expected with a product made by many manufacturers, there is some variation in the weave of the fabric received from time to time. The following details may be taken as average:—

Thickness—1½ to 2 mils.
Ends—128-130, 20 denier yarn.
Picks—90-100, 18 denier yarn.

Tensile "as received" in warp direction—15 lbs./1 in. width.

Tensile "as received" in weft direction—13½ lbs/1 in. width.

Silk has the advantage as compared with other textiles used for insulation of being more elastic. This property enables it to bed more readily to varying curves.

A peculiar feature is that although the silk thread is solid, whereas that of cotton is tubular, silk is the more hygroscopic under normal conditions. In spite of this its electrical properties are superior to those of cotton, even in the unvarnished condition. Besides being used as a backing for mica tape it is frequently employed for protecting the edges of mica washers and is wrapped on the outside of micanised bars, such as are used for brush spindles and carrying terminals.

RAYON (ARTIFICIAL SILK)

Until the war with Japan resulted in silk becoming very scarce in 1942, rayon (or artificial silk) had never been seriously considered by the electrical industry. This was chiefly because the type of fabric needed was much thinner than was normally made, and the physical characteristics of much of the rayon yarn were not suitable.

In July 1942 the British Electrical and Allied Manufacturers Association appointed a technical committee composed of members of the firms which manufacture rayon yarns, silk and rayon weavers, and users of silk in the electrical industry. It was the business of this committee to agree upon suitable rayon fabrics and publish specifications for them. This difficult work was completed in the remarkably short time of six months, during which many special fabrics were woven and tried out for various purposes.

MANUFACTURE OF RAYON YARNS.

There are several types of rayon yarn, not all of which are suitable for the electrical industry. Those chosen by the committee are known as strong yarns and are particularised under the names Durafil, Tenasco, and Fortisan. All three are in the class known as regenerated cellulose, i.e., the cellulose in the cotton or wood, whichever is used as the raw material, is first broken down into a chemical compound and by subsequent processes reformed into cellulose.

TENASCO AND DURAFIL are high tenacity rayons made by the viscose process. The basic raw material is wood pulp or cotton which is first steeped in caustic soda, pressed to remove excess caustic then shredded to form alkali cellulose crumbs. The alkali cellulose is next treated with carbon disulphide and the resulting cellulose xanthate dissolved in dilute caustic soda to form a very viscous liquid known as viscose.

The viscose is carefully filtered, de-aerated and ripened to the correct stage prior to spinning. The spinning operation consists of extruding the viscose through small holes in a spinnerette immersed in an acid bath which coagulates the viscose. The resulting thread is subjected to a controlled stretch and collected into a centrifugal box which forms a yarn package known as a "cake." The cake is passed through various solutions to remove impurities and finally washed and dried.

The main difference between Durafil and Tenasco is in the physico-chemical conditions of coagulation and stretching whereby Durafil is given an extremely high molecular orientation whereas *Tenasco* has a somewhat lower orientation. The filament sizes of the two yarns are very different, being in the ratio of approximately 7 to 1. *Durafil* being much the finer. The physical properties of the yarns are very different as a result of their different molecular characteristics.

e.g. :—

Durafil 5.0 to 6.0 gms./denier 6.0% Extension.
Tenasco 3.5 gms./denier 18.0% Extension.

Chemically they are both the same, i.e., regenerated celluloses.

FORTISAN YARN is regenerated from cellulose acetate. The cellulose acetate is made by the acetylation of purified cotton linters in a mixture of acetic acid and acetic anhydride in the presence of a suitable catalyst. Cotton linters are the short hairs left on the cotton seed after the removal of the longer ones used in making cotton yarns for weaving. The resulting product is a syrupy liquid, from which cellulose acetate is precipitated as a flaky material by further treatment. This material is thoroughly washed and the cellulose is regenerated by the action of alkali. The resulting product is spun into filaments through holes in steel plates and wound into threads.

During the spinning process the filaments are stretched so that they are available in a range of sizes, the finest of which are considerably smaller than those of natural silk.

SPECIFICATIONS FOR RAYON FABRICS.

The specifications to which reference has been made have not been published in the form of British Standards. They were circulatd to all interested parties and have been accepted as defining what purchasers needed when ordering fabric for electrical purposes.

The titles of the specifications are :—

Provisional Fabric Specification No. SS1.
Rayon Fabric for use Varnished.
Provisional Fabric Specification No. SS1A.
Rayon Fabric for use Unvarnished.

Specification SS1 is for fabric used in making varnished or "oiled" fabric, frequently used when slit into tape for high voltage insulation.

Specification SS1A was expressly drawn up for machine manufacturers, principally for backing mica tape. Either type may be used for this purpose, and often SS1 is accepted if SS1A is not available, although the price of SS1 is greater.

The yard for warp and weft is to be of 30 denier for both types. The difference between them is that SS1 has 100 ends and 100 picks, and SS1A 100 ends and 60 picks. Both are not more than 2 mils thick.

The weave and finish is to be uniform and reasonably free from unevenly tensioned selvedges, weaving faults, and broken filaments protruding on the surface. The normal width is $36/36\frac{1}{2}$ in. and it should be obtainable in lengths of 100 yards, wound on cardboard tubes. A reasonable percentage of lengths less than 100 yards may be accepted by agreement.

These fabrics can be obtained in the loom condition or scoured. Tests have shown that the sizes used in the yarns for assisting weaving are not objectional from an electrical point of view. In the scoured material the threads slip more easily when the material is being brush varnished so that material in the loom state is preferable. The thickness of these fabrics is about 1.7 mils and the tensile strength is greater than that of silk. They have been used extensively since 1943 and have been quite satisfactory when employed as a backing for mica and similar purposes.

Silk and Rayon Tapes.

Selvedge edged tapes are sometimes used for the taping of small armature coils and field coils, they are generally purchased in the open market against sample. Their thickness is about 3 mils and widths are usually $\frac{3}{8}$, $\frac{1}{2}$, $\frac{5}{8}$, $\frac{3}{4}$ and 1 in.

It is advisable to ensure that these tapes are not made of cellulose acetate rayon which is liable to dissolve in varnishes containing methylated spirit, and they may decompose if worked at 90°C. or even lower temperatures. A rough test may be made by holding a lighted match near to the end of the tape so that it is well heated, but not burnt; if it is cellulose acetate the threads will fuse and form blobs; there will also be a smell of acetic acid.

Regenerated cellulose, which should be used for these tapes, when heated with a lighted match will emit a smell like that of burning paper. As a rule it does not form globules, but if it does, the smell should be sufficient indication of its nature.

The solubility of the tape in acetone provides a further check. Cellulose acetate is completely soluble whereas regenerated cellulose is not.

A cheaper type of tape is provided by slitting rolls of silk or rayon fabric into tape. The sides of the rolls of tape are rubbed on abrasive paper to remove the fluff and are then coated with a suitable adhesive to prevent the tape coming asunder. Such tape serves many useful purposes; the edges generally exhibit roughness when the tape has been applied, so that discrimination is necessary in its use.

CHAPTER IX

FIBRE GLASS AND ASBESTOS FABRICS AND TAPES

FIBRE GLASS PRODUCTS.

The introduction of fibre glass products and the use of varnishes which will work at higher temperatures than the industry has hitherto been accustomed to will eventually bring about a revolution in the technique of designing and making electric machines. As will be seen by reference to chapter XIV it is now possible to fabricate insulation which will work indefinitely at higher temperatures than will be considered desirable for normal service.

MANUFACTURE OF FIBRE GLASS YARN.

The first attempts to make fibre glass yarn were made in Bohemia in 1904. It was developed as a heat insulation. In 1914-18 the Germans used it in place of asbestos for thermal insulation.

In later years, the Americans concentrated on the problem and succeeded in making glass yarn which could be woven into fabrics and tapes. Manufacture of the yarn to U.S. patents began in this country about 1938.

Two kinds of glass yarn are employed in the weaving of fabrics and tapes—continuous filament yarn, and staple filament yarn. The thin fabrics used in the electrical industry are woven with continuous filament yarns, the filaments having a diameter of only 0.0002 in. to 0.00025 in., i.e. about one tenth the diameter of human hair. It requires ten million yards of single filament to make one pound weight of yarn.

Thicker fabrics and tapes are woven with staple yarn, which consists of filaments 6 in. to 15 in. long and rather larger in diameter.

The basis of glass is silica, i.e. sand, but this by itself is not easy to process so other substances are added. These comprise, among others, soda ash, dolomite, felspar, burnt lime, boric acid. Different mixtures are used, depending upon the purpose for which the glass is required. For electrical purposes, it has been found that alkali metal oxides, e.g. soda and potash, should be avoided and yarn for electrical fabrics is made of alkali free glass.

After the silica and other ingredients have been fused and thoroughly mixed, and laboratory tests have been made to certify that the mixture is satisfactory, the molten glass is fed into a marble making machine. This machine produces marbles weighing one third of an ounce. These are fed into the furnace from which the filaments are drawn. The furnace is made of platinum and is heated by the passage of current through it. The marbles are fed into it at regular intervals, so that the temperature of the furnace is not appreciably altered since this would affect the diameter of the filaments.

Figure 24 is a schematic diagram of the plant. The furnace is carried on a platform many feet above ground level, and the filaments are drawn from 102 nozzles in the underside by means of a winding drum. The holes in the nozzles are $\frac{1}{32}$ in. diameter and the winding drum runs at such a speed that the issuing molten glass is stretched until it is only .0002 in. diameter. The drawing speeds are as high as 10,000 ft. per minute. In their descent the filaments are gathered together into a vee shaped guide where they are lubricated with an oil emulsion to reduce

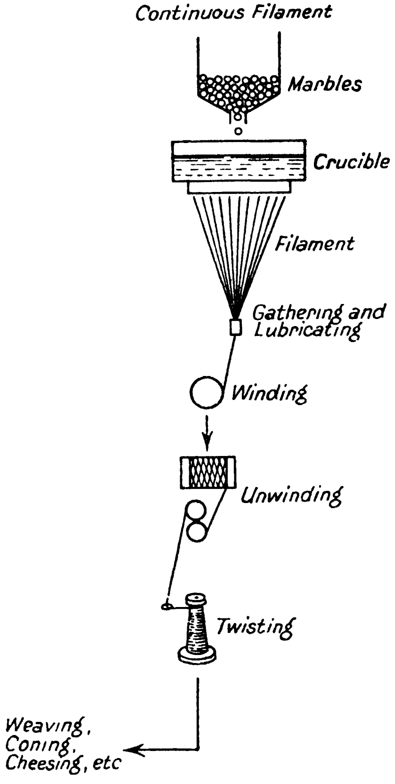

FIG. 24—Diagram representing the production of continuous filament glass yarn. (By courtesy of Fibreglass Ltd.)

abrasion. They are all wound together on the same drum, which, when full, is transferred to machines where the filaments are unwound and twisted in readiness for weaving.

There is a simple explanation for the use of 102 filaments. The yarn is guaranteed to have 100 filaments plus or minus 2 per cent and the employment of 102 nozzles allows of four filaments breaking before the drawing operation need be stopped.

CLASSIFICATION OF YARN.

Two systems for classifying yarns, the count for cotton, and the denier for silk and rayon have already been mentioned. Another system is employed for continuous fibre glass; it is the number of hundreds of yards of yarn per pound. Only one thread of 102 filaments is made. There are 90,000 yards of this thread in a pound, so the count is 900s. Before the yarn can be used for textiles the filaments must be twisted together and one such twisted thread is designated 1/900s. Two of these threads twisted together give 2/900s, and if two pairs are twisted together they are indicated by 2/2/900s, and so on.

WEAVING OF FABRICS.

The weaving of thin glass fabrics called for considerable skill and patience at the outset. Unlike silk and rayon, glass yarn has practically no extensibility, and whilst it is very strong in direct tension it will snap readily under certain conditions. For example, threads cannot be joined by tying; they have to be cemented with a quick-drying cement. These thin fabrics can only be woven on silk looms which are in first class condition; cotton looms are entirely unsuitable. Special care has to be taken in setting up the warp threads because of their low extensibility; if they are not evenly tensioned throughout trouble will be experienced when the loom is started. Some of the warps may break and the fabric will not be uniform for some considerable distance from the start.

In chapter XV will be found information upon varnished seamless bias cut tapes and their desirability in many cases. Until very recently, it was not possible to weave glass fabric in the circular form necessary for slitting into bias sheets. This has now been accomplished with 3 mil material, and it may be that this very useful type of tape will shortly become available.

Alarm is sometimes felt about the effects of the glass on those handling it. Some may feel a little skin irritation at first but this disappears after a few days and nothing serious has been known to result. It has been found that brunettes are less susceptible to irritation than blondes!

It is stated that the dust from fibre glass is not harmful to the lungs and will not induce silicosis. In any case, the amount that may be inhaled over a long period is exceedingly small, even if operators are using yarns or fabrics constantly.

WOVEN GLASS FABRIC.

This is manufactured in long lengths 36 ins. wide. Thickness 1½, 2, 3, 5 mils.

Although the Americans invented and produced the yarns, they were unable to weave thinner cloth than 2 mils. The introduction of 1½ mils fabric is due to a British weaver.

Until varnished, the electric strength of glass fabrics is little different from other types of fabric. When varnished, they are similar to other textiles in that they will tear readily unless the varnish film is soft and pliable.

Extensive tests have shown that coils taped or wrapped with fibre glass tape or cloth and consolidated with varnish will stand a considerable amount of mechanical knocking about without the material crushing or fracturing, provided it is not wrapped over sharp edges.

WOVEN GLASS TAPES.

These are obtainable in widths of ⅜, ½, ¾ and 1 inch. All widths are obtainable in 3, 5, 7 or 9 mils thickness. Length, in a roll, 50 yards.

Glass tapes are unaffected by any temperature ever likely to be met with in electrical machines during normal operation. Their tensile strength is several times greater than that of tapes made with any other material. The extensibility of glass tape is very low, being not more than 2 per cent. The dielectric strength in the unvarnishd condition is that of the air spaces between the threads, so that it is no better than cotton or other untreated woven products. When varnished the electric strength is largely governed by the quality of the varnish used. The advantage of glass over other materials is that it enables one to make use of the newer types of synthetic varnishes, which can be worked at temperatures in the neighbourhood of 150°C. or a little higher. Whilst such temperatures are not common at present, they may be met with under certain conditions. Care is required in using the thin tapes, particularly the 3 mil size, as the weft thread is liable to slip when pulling the tape between the thumb and fingers during hand taping.

A specification of the weave is not available; there are few weavers of these tapes and one generally accepts what is offered, especially as the thin tapes are produced almost exclusively for electrical purposes.

ASBESTOS.

Asbestos is a fibrous mineral found in veins in the older crystalline rocks. It is chiefly obtained from the Quebec area of Canada, Rhodesia and Russia. The variety of asbestos used for tapes and fabrics is a hydrated silicate of magnesium. The fibres are elongated crystals varying in length from an inch to more than a foot. They are of much smaller diameter than cotton or silk fibres, and smooth, whereas the others are rough. These features make asbestos more difficult to weave and result in a lower tensile strength. Many grades of asbestos contain impurities which impair their electrical properties, one of the most objectionable being magnetic-oxide of iron. However, selection of suitable grades and subsequent cleaning operations enable the industry to produce highly purified forms of asbestos products. Such treatment is not necessary for other trades and it is most important when ordering to state that the material is required for electrical insulation.

WEAVING ASBESTOS.

In order to weave asbestos satisfactorily, varying proportions of cotton, normally up to 10 per cent, but sometimes as high as 15 per cent are added during the process of making the yarn. The presence of cotton, however, is not of serious consequence since such mixtures come within the category of class B insulation. Although asbestos products have a damp feeling and one receives the impression that they are very hygroscopic, the loss in weight of asbestos tape when dried at 100°C. is normally about 1.5 per cent whereas cotton tape loses as much as 8.5 per cent.

ASBESTOS CLOTHS.

It is important to specify that these are required for electrical purposes, otherwise fabrics of a conducting nature may be supplied. The chief use for these cloths is as dirt excluding hoods for covering the end windings of traction and mill type motors. For such a purpose the fabric should be thin and fairly closely woven.

A suitable cloth is 20 mils thick and has 28 ends and 18 picks.

ASBESTOS TAPES.

Owing to its great importance, it is again stressed that these must be ordered to be suitable for electrical insulation, if trouble is to be avoided.

ELECTRICAL TESTS ON ASBESTOS TAPES.

Although asbestos tapes had an unenviable reputation for electrical conductivity in the past, present day products are extremely good. Thus if 1 inch tape, either 10 or 15 mils thick and including the type with cotton weft, is conditioned for 18 hours at 15°C. to 25°C. in an atmosphere of 65 per cent relative humidity (Appendix A), there ought to be no difficulty in obtaining the following results:—

Resistance in warp direction at 500 volts D.C. (1 in. between electrodes), not less than 20 megohms.

Should withstand 10 kV. for 1 minute between electrodes 1 in. apart.

The electrodes for this test consist of brass clamps which bolt or clip squarely across the tape. It is usual to suspend the tape freely in air by one pair of clamps, the other pair being attached to the lower end. By this means the possibility of secondary leakage paths is avoided.

Another test, for conducting particles, is to place the tape on a flat metal surface and run a metal roller over it, a voltage of 230 being applied between the roller and plate, with a 15 watt, 230 volt lamp in series to limit the current. The tape should show no conducting paths in a length of 6 yards.

WIDTH, THICKNESS AND WEAVE.

Asbestos tapes for electrical purposes are obtainable in widths from ½ in. to 2 ins. by increments of ¼ in.

Two thicknesses are available, 10 and 15 mils.

Length in a roll, 36 yards.

The 10 mil tape may be obtained with asbestos warp and weft, or with asbestos warp and cotton weft. The latter is considered class B insulation just the same as the all asbestos tapes. The 15 mil tape is made only with asbestos warp and weft. All the tapes may be up to 2 mils above nominal thickness.

Representative weaves are :—

Thickness	*Threads per inch*	
mil	*Warp*	*Weft*
10	30	20
15	30	18

CHAPTER X

DRYING-OIL BAKING IMPREGNATING VARNISHES. HEAT RESISTING INSULATING ENAMELS

It has long been known that, apart from mica, no insulation employed in machines is of much use unless it is impregnated or coated with a good quality insulating varnish. Indeed, it may be said that the varnish is the insulant, the solid material, be it presspaper, tape or other material, being merely the carrier for the varnish. It is known that the electric strength of a pure varnish film is greater than that of an impregnated carrier of equal thickness; e.g., the electric strength of enamelled wire is several times greater than that of varnish impregnated d.c.c. wire, although the thickness of the d.c.c. may be three or four times that of the enamelled coating. Confirmation of this is given on page 142.

Drying-oil varnishes are those which dry largely by oxidation, so that if stoving or baking is necessary care must be taken that an adequate supply of oxygen is available by arranging for a slow but constant change of the air in the stove. More will be found upon this problem in Chapter XXI.

The formulation of varnishes is a highly technical and complex subject. Varnish manufacturers have their own formulae, which in most cases are jealously guarded secrets. In fact, when new varnishes are offered to customers the varnish manufacturer sometimes declines to give even a hint of the constituents.

It is not absolutely essential that a user should be given some idea of the composition, since if it is a new varnish its value can only be assessed by laboratory tests at the outset followed by reports upon its behaviour in service. A knowledge of its formulation does not enable one to say that a certain varnish will be a success; slight additions of different resins or chemicals to well-known mixes may alter completely the qualities of the products.

Nevertheless, it is an advantage to have some knowledge of the manufacture of varnishes, and a thorough knowledge of their testing.

DRYING-OIL BAKING INSULATING VARNISHES.

These varnishes have been in common use in the electrical industry for 30 years or more, and still form the bulk of those employed. They consist essentially of vegetable drying-oils, such as linseed oil or china wood (sometimes known as Tung Oil), resins such as copal and rosin, metallic driers among which litharge and cobalt or manganese naphenate are prominent chemicals, and thinners or reducers such as white spirit, petrol and benzine.

Linseed oil is extracted from the seed of a flax plant and comes largely from the United States and South America, Russia and India. Tung oil is obtained from the seed kernels of Aleurites corda, a tree indigenous to China. There are many types of copal but the one most frequently used is Congo Copal. This comes from the Dutch and Belgian Congo. It is a fossil gum from trees which grew centuries ago. Rosin, or colophony, is a residue from the distillation of turpentine exuded from pine trees. Petrol, benzine and white spirit all come from the distillation of crude oil. Mixtures of these substances produce the familiar clear or amber coloured varnishes, and bitumen is added to obtain black baking varnishes.

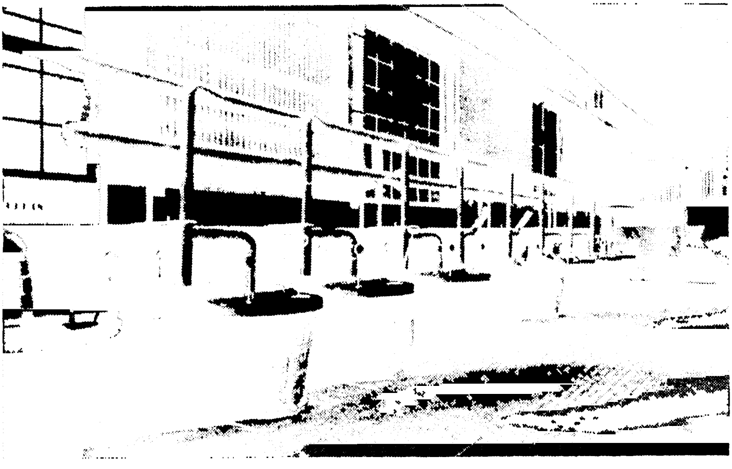

FIG. 25—Varnish Kitchen. (The Sterling Varnish Co. Ltd.)

MANUFACTURE OF DRYING-OIL VARNISHES.

Although the making of varnishes requires great skill and careful control of processes, a visit to a varnish kitchen—the name given to the building in which they are mixed—is devoid of the movement and visual attraction to be found in an engineering or winding shop. All one sees, as shown by Fig. 25, is a series of iron vessels, usually heated by gas rings, and fitted with covers for fume extraction. Nevertheless the processes are interesting and worthy of description.

Rosin and copal are both relatively insoluble in the drying oils when cold and are melted to facilitate solution. Rosin need only be melted, but copal must be carried well beyond its melting point, an operation known as gum running.' This process requires great care. If the copal is not fused at the right temperature the correct amount will not go into solution in the oils; if it is overheated the varnish will be dark in colour and inferior in quality. While the gum is being run the oil, or mixture of oils, is being heated in a separate vessel. At the appropriate time the oil is slowly added to the fused gum with constant stirring. The temperature may be as high as 290°C., during this part of the process.

When the mixing is complete, the temperature is allowed to fall to about 150°C., and the driers are then added, again with constant stirring. The final addition is that of the thinners, which takes place after the temperature of the varnish has fallen below the boiling point of the solvent. The varnish is next strained to remove any undissolved particles, after which it is passed through a filter press or centrifuge. Amber varnishes are often cloudy at first and may have to be stored at constant temperature for from three to six months to clarify.

TESTING OF DRYING-OIL VARNISHES.

Since the life and proper functioning of machines is largely dependent upon the varnish, careful and frequent tests are essential. Two British Standards are in being to serve as guides.

BS. 119-1930, Clear Baking Oil Insulating Varnish for Electrical purposes.

BS. 514-1933, Baking Insulating Varnish (Bitumen type) for Electrical purposes.

Similar tests are applied to both types of baking varnish, but the figures with which they have to comply differ; they will be recorded as necessary. When tests are being made it is essential that the varnish is at the specific gravity or viscosity recommended by the maker.

SPECIFIC GRAVITY.

The specific gravity at 20°C. of the varnish as received may be the subject to agreement with the supplier. In general the specific gravity at which it should be used for certain purposes is specified by the maker.

VISCOSITY.

The measurement of viscosity in poises as detailed in BS. 119 and BS. 514 is not suitable for workshop tests. More serviceable methods are discussed in Chapter XXI. Most varnish makers will deliver varnishes to viscosities measured by one of the methods described, and the limits for the viscosity should be agreed.

FINISH.

The varnish should produce a uniform, smooth, glossy surface when dried on paper for the drying time test described later.

VOLATILE MATTER.

The weight of volatile matter driven off in the following test, computed on the original weight of the varnish, unless otherwise agreed, should not exceed :—

40 per cent for clear varnishes.
50 per cent for bitumen type varnishes.

Some people speak of the "solids" in a varnish, instead of the volatile matter. To comply with the above the solids should not be less than 60 per cent and 50 per cent respectively. It will be understood that this is a most important feature.

The test is made by weighing one or two grammes in a weighed glass or aluminium dish about 3 ins. dia. The thinner is driven off by heating over a hot water bath after which the dish is placed in an oven at 105°C. (± 5°C.) for 1 hour. It is then cooled, weighed, and returned to the oven for further heating. The weight is taken after each half hour and the final weight is that at which there is no alteration, or an increase occurs due to oxidation.

DRYING TIME.

The drying time of either type should not exceed 8 hours when tested on tissue paper of about 1 mil thickness. A special sulphite wood pulp paper for the purpose may be procured; the name of the supplier may be ascertained from the Director, British Engineering Standards Institution.* For normal routine tests Jap tissue or the Super Flexrope paper mentioned in Chapter VI will serve in place of the special paper, if it is not desired to obtain the latter.

A convenient size of paper is 6 ins. × 4 ins. It is immersed in the varnish for about one minute, care being taken to remove all froth. The depth of varnish should be about $\frac{3}{4}$ in. The specimen is drawn out of the varnish at the same rate as the excess of varnish slips from the surface. It is then allowed to drain for thirty minutes at room temperature (about 20°C.). The sample should be hung vertically for draining and drying, and to prevent the paper crinkling it is advisable to attach a clip to each end of the specimen before immersion and leave them in position during the drying period. The specimen is next dried in an oven at 95°C. to 100°C., unless the maker recommends a higher temperature. The air content of the oven should be changed not less than three times per hour by passing fresh air through.

The varnish is considered dry when it passes the following test. A circular piece of No. 4 Whatman filter paper, $1\frac{3}{8}$ in. dia. is applied approximately to the centre of the specimen, and pressed

*28 Victoria Street, London, S.W.1.

on to the varnish film by a weight of 1 lb. having a base 1 inch in diameter. The filter paper must not adhere to the film. It is usual to turn the specimen upside down, and if the filter paper drops off the varnish is considered to be dry.

ELECTRIC STRENGTH AT 90°C.

This should be not less than the approximate value shown by the curve in Fig. 26. This curve is applicable to both the clear and bitumen types of varnish. It is not usual to measure the electric strength of a varnish film, but of the varnish applied to paper. Specimens are prepared as for the drying test, but are given a second dip and drying after the first one. They are drawn out of the varnish by the opposite end and hung up in the reverse way to drain and bake.

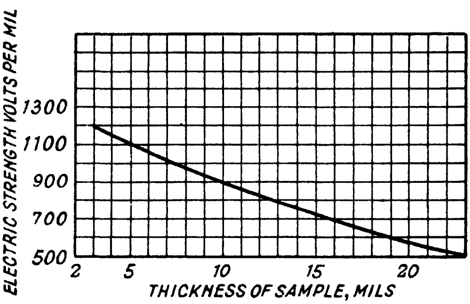

FIG. 26—Electric Strength (Proof Test) of varnished tissue paper.

The test is carried out in air at a temperature of 90°C. (± 2°C.), preferably within half an hour of the completion of the drying of the second coat of varnish. If this is impracticable it must be carried out within 24 hours, and the specimen must be heated at 90°C. (± 2°C.) for half an hour immediately before the voltage is applied.

The electrodes are of the type illustrated in Appendix D. They are raised to the testing temperature before the specimen is placed in position. After putting the specimen between them the set-up is kept at the testing temperature for not less than one minute or more than five minutes before voltage is applied. Some varnishes soften when hot and adhere to the electrodes. If this occurs, discs of tinfoil cut to size may be interposed between the specimen and the electrode.

The test is made with alternating current as described in Appendix D. The voltage is raised at a uniform rate from zero to the breakdown voltage at such a rate that the specimen is punctured in about 10 seconds. The electric strength should be not less than that shown in the curve in Fig. 26. The thickness of the specimen is determined from the mean of three measurements taken as close to the point of puncture as possible, and from this the breakdown in volts per mil is computed. Ten puncture tests are made and the mean of the ten results is taken as the electric strength of the varnished paper in volts per mil.

RESISTANCE TO MOISTURE.

Resistance to moisture is another important quality. Specimens are prepared as just described for the electric strength test and subjected for 24 hours to a controlled atmosphere of not less than 95 per cent relative humidity (Appendix C) at 15°C. to 25°C. The same type of electrodes are used, the test being carried out in the controlled atmosphere.

The electric strength of the varnished paper should be not less than 400 volts per mil for clear varnishes and not less than 500 volts per mil for bitumen type varnishes. The mean of ten readings should be obtained as described in the electric strength test.

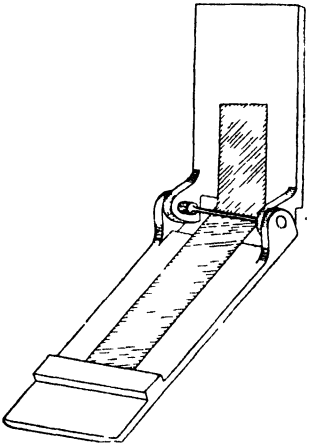

FIG. 27—Apparatus for ageing test of varnish film.

AGEING.

The varnish film should show no sign of cracking or decomposition after being maintained at 100°C. to 105°C.. for 100 hours in the case of clear varnishes and 115°C. to 120°C. for 100 hours in the case of bitumen types, and then bent as described below. For testing the ageing properties the varnish is applied to one side of a piece of copper foil about 6 ins. × 2 ins. and 10 mils. thick. The foil should be flexible enough to withstand without cracking 30 bends (15 in each direction) round a rod of $\frac{1}{8}$ in. dia., using the apparatus shown in Fig. 27. The foil is freed from grease by cleaning with benzole.

The varnish is applied to one side of the foil only by flowing it over the surface so as to produce a uniform film. It is allowed to air dry in an upright position in a clean atmosphere at 15°C. to 25°C. It is then stoved for 2 hours at 100°C. to 105°C., the air content being changed not less than three times per hour.

A second coat of varnish is applied, air dried and stoved as before, but with the foil placed in the reverse direction, i.e., top to bottom.

After removal from the oven the foil is allowed to cool for one hour when the thickness of the film is determined. It should be not less than 5 mils or more than 7 mils. If less than 5 mils, further coats are applied as before, the final coat being stoved until dry; the stoving period for the final coat is not to exceed 8 hours.

The varnished foil is next heated for 100 hours at 100°C. to 105°C. if coated with clear varnish, and at 115°C. to 120°C. if coated with the bitumen type, the air in the oven being changed not less than three times per hour. After removal from the oven the foil is allowed to remain at room temperature for one hour, after which the test is made at room temperature.

For testing the varnish film the foil is bent double over a rod $\frac{1}{8}$ in. diameter by means of the apparatus illustrated in Fig. 27. It is placed so that the varnish film is on the outside of the bend, and one complete bend of 180° is performed in two seconds. Two bends are made, each at a different place on the foil; there should be no sign of cracking or decomposition.

As copper foil will sometimes develop minute hair cracks care must be taken, if cracks appear, to ascertain whether they are in the copper or the film.

Whilst a single bend at two places suffices for the approval of a varnish, it is usual to make more than one bend at each place and record the number made before cracking occurs. Such a procedure is useful when comparing different varnishes.

ACIDITY OR ALKALINITY OF VARNISH FILM.

The pH—value of the varnish film should not be less than 4 for clear baking oil varnishes and 3.8 for the bitumen type. It should not exceed 7.5 for both types.

The film is prepared by coating with varnish a piece of tinplate amalgamated with mercury and baking it as described in the section headed "Drying Time." Most films will readily peel off when prepared in this manner.

One gramme of the film is digested at about 70°C. for one hour in 25 mils. of freshly distilled pure water, free from carbon dioxide, and contained in a hard glass tube. The water is then decanted from the film and its pH-value measured at room temperature.

The use of what is known as a universal indicator for ascertaining the pH-value is satisfactory in most cases and is recommended for those not accustomed to making this test. Special apparatus is required and detailed instructions for using it may be obtained at the time of purchase. In certain circumstances, and especially if the decanted liquid is not colourless, the pH-value cannot be found by the use of an indicator. It is then necessary to use a potentiometric method. The special apparatus and technical knowledge necessary for making this test are too complex to be described here.

There is another method of measuring the acidity of the water extract, viz., by titration. In this method the quantity of potassium hydroxide (KOH) required to neutralise a given quantity of the extract is measured. The titration method is not specified in the British Standards.

The difference between the two methods is that the pH-value is a measure of the intensity of the acidity present, whereas the titration test is a measure of the volume of acids present.

The titration test does not necessarily indicate the objectionable nature of the acid. For example, equivalent quantities of hydrochloric acid and boric acid in solution—say 10 c.c. of N/10 solution of either—require the same quantity of KOH for neutralisation, although hydrochloric acid is a much more destructive acid. This is shown by its pH-value being much lower than that of boric acid.

Thus it will be seen that for normal circumstances the measurement of the pH-value is the more desirable alternative and has the advantage of requiring much less time and skill.

If it is desired to obtain a complete comparison between two or more varnishes both the above tests may be employed with, in addition, a determination of the conductivity of an aqueous extract, made as described in Appendix E.

Effect of Oil.

In general oil does not get on to the windings of machines so that the oil resistance of varnishes is not of great importance. Sometimes, however, machines have to run in an atmosphere containing oil fumes, e.g., diesel engine driven generators, or machines in oil refining plant. In such cases it may be desirable to ensure that the varnish is not liable to be affected. Bitumen type varnishes are more likely to be affected than the clear type.

A quick and very rough test is to put some lubricating oil on the varnished foil used for the ageing test and rub it with the finger. A more scientific test is given in Appendix F.

Flash Point.

This should not be less than 23°C. when the varnish is tested in the Abel apparatus.

Since the quality of varnishes is of paramount importance it is advisable that all these tests, with the exception of the flash-point test, should be made at fairly frequent intervals.

HEAT RESISTING INSULATING ENAMELS.

These are of a grey or blue-grey colour. They consist of a normal drying oil varnish to which suitable pigments have been added. It will be obvious that they cannot be expected to work at appreciably higher temperatures than the varnishes from which they are made. When properly applied these enamels tend to fill the interstices in windings better than unpigmented varnishes thus aided the conduction of heat from the inside to the outside of coils. In this manner they may enable slight increases in output to be obtained, but this is problematical.

They are frequently used for the impregnation of large field coils wound with rectangular or square d.c.c. wire and in which the depth of the winding is too great for thorough impregnation in bitumen—the usual medium employed for field coil impregnation. In such cases the enamel is brushed on layer by layer as winding proceeds, the finished coils being baked for 12 or more hours to solidify the enamel. Coils treated in this way give excellent service under very exacting conditions.

Traction armatures are often finished with this type of enamel because it presents a hard moisture-resisting finish which is unaffected by oil and grease when thoroughly dry.

Another use is for the filling of air spaces in the end windings of high voltage machines insulated with class A insulation. Layers of varnished cotton (empire) tape are employed for the insulation and the enamel is brushed thickly on each layer, any excess being squeezed out by the application of the next layer of tape.

It should be remembered that the pigment will not thoroughly permeate a fibrous insulation, such as the cotton covering on wire unless it is well brushed in. If it is used in a fairly full-bodied condition the pigment and varnish will remain on the surface of covered wire if dipped in it and only a small amount of stained thinners will penetrate the covering. Whilst a somewhat better penetration results if the enamel is thinned the protection provided is not so good as that resulting from the use of a straight varnish.

This type of enamel will skin over if applied thickly, and the underneath may remain soft for months. Whilst this property is useful when the enamel is brushed between layers of tape in high-voltage windings, it is a disadvantage if used as the finishing coat of windings. Care must be taken not to apply it too thickly in such cases.

CHAPTER XI

SYNTHETIC RESIN VARNISHES AND INSULATING ENAMELS

These comprise oil modified synthetic resin varnishes, and high-temperature varnishes which are generally composed of a synthetic resin dissolved in a suitable solvent.

Until about ten years ago the oil base varnishes described in the previous chapter appeared to meet the needs of machinery manufacturers. They lasted well at the temperatures permissible for class B insulation. There was very little difference in the quality and performance of varnishes made by all the well known manufacturers and a state of tranquility seemed to be present since routine testing, rather than the frequent testing of new types, was the order of the day.

The arrival of fibrous glass, however, showed the need for varnishes which would stand higher temperatures, and ever since varnish manufacturers have been producing new types which incorporate synthetic resins. An enormous amount of time and money has been spent upon the research necessary for producing such varnishes and machinery manufacturers have contributed liberally by making frequent and long-period tests.

Whilst there is no accepted definition of a high temperature varnish we may consider the chief requirement to be that it shall work for an indefinite period at not less than 150°C. Many of the varnishes submitted for trial have not possessed this qualification but have proved to be superior to the normal oil base baking varnishes in moisture resistance. In consequence consideration has been given to the use of such varnishes for the impregnation of windings insulated with the commonly used insulations. In spite of the undoubted superiority of some of these varnishes the changeover to them must of necessity be slow for three reasons.

Most baking ovens are constructed to operate at 100-110°C., and many of the new varnishes require two temperatures. A short drying of say 2 hours at 80°C. followed by a long bake at about 135°C. It is not easy to change over to the higher temperature. The second reason is that there is no means of forecasting with certainty how a new varnish will behave during many years of service. Varnishes which have exhibited superior properties during laboratory tests have been known to fail badly after a comparatively short life in service, and large electrical manufacturers cannot take the risk of a complete and immediate changeover in varnish. There must be a period of years during which the new varnish is gradually introduced. The third reason is the rapidity with which new varnishes are now being submitted for trial to electrical manufacturers. It is not a new experience these days to receive a sample of a varnish which preliminary tests indicate is better than one which is just about to be put into use.

OIL MODIFIED SYNTHETIC VARNISHES.

These varnishes generally have better bonding and moisture resisting properties than the oil-base and gum types described in the previous chapter. They are reliable for service up to 120°C. The resins are mostly of the phenolic type, i.e., phenol, cresol or xylenol in combination with formaldehyde. They do not have to be heated like the natural gums but are directly soluble in heated drying oils like linseed or tung. Metallic drying agents of the kind used in the ordinary baking varnishes are added, but different thinners are necessary. These usually consist of xylol, coal tar naphtha and benzol, although a few may be thinned with white spirit. Unlike the oil-base varnishes, oxygen is not very necessary to enable them to set. Setting is due to polymerisation in which there is interaction between the resin component and oil during the baking of the impregnated coils. It is most important that these varnishes are baked at the temperature specified or complete polymerisation will not take place, in which case the moisture resistance will be poor.

Oil modified alkyd (glyptal) resin varnishes are also made. These are even better than the phenolic types for moisture resistance. They take longer to dry, but give a film which is more flexible after prolonged heating.

TESTING.

The testing of oil modified synthetic varnishes is similar in routine to that employed for the drying oil varnishes described in the previous chapter, except that the temperatures employed differ. The specimens are baked at the makers' recommended temperatures.

Since these temperatures do not, as a rule, exceed 135°C. tissue paper can be used as it does not depreciate to any extent during the comparatively short baking period. It will be found that a good quality varnish of this type will have a much higher electric strength when tested at 90°C., than is required by the curve given in Fig. 26 for ordinary baking varnishes.

INSULATING ENAMELS.

Pigmented varnishes of the alkyd type are now superseding the heat resisting insulating enamels described on page 71. They have the advantage that the service heat from the windings causes them to polymerise and harden right through.

HIGH TEMPERATURE VARNISHES.

Under this heading we refer to varnishes which are considered capable of working at 150°C., or more for a long period. It must be admitted of course that we do not know with certainty how these varnishes will behave as they age. No laboratory test can be conclusive as it is impossible to compress a working life of ten years or more into the space of a few weeks' tests. Neither can a Laboratory test on a machine reproduce the conditions met with in service, such for example as the intake of dust and wet experienced by traction motors. However, the rigorous tests to which they have been submitted lead us to expect a reasonably long life.

For these varnishes resins of the alkyd type, of which the best known is glyptal resin, are often used. They are dissolved in a solvent such as butyl alchohol mixed with white spirit or coal-tar solvents. The ordinary drying oils are not used but drying and non-drying oil fatty acids are employed for the modification of the resins. Another type is composed of urea-formaldehyde resin mixed with a plasticising alkyd resin.

As the baking temperatures of these varnishes is in the region of 135°C. many of the tests may be carried out in the usual manner on varnished tissue paper. For tests at higher temperatures the thinnest woven glass is used in place of the paper. Ageing tests are carried out at temperatures as high as 250°C. Naturally, these varnishes do not survive many days at such a high temperature, but the fact that they will retain a certain amount of cohesiveness after a few days is a hopeful sign.

The electric strength of some of these varnishes is very good. One varnish on glass cloth had an initial strength at 90°C. of 1150 volts/mil. After 24 hours at 150°C. it was over 1300 volts/mil, and had improved slightly after 6 days at this temperature. At 200°C. it was about 10 per cent below the initial figure after 24 hours and had fallen a further 10 per cent at the end of 6 days.

CHAPTER XII

FINISHING VARNISHES

Finishing varnishes may be divided into two types, baking and air-drying. The air-drying varnishes may be sub-divided into two classes; those with a methylated spirit solvent and those with a non-alcoholic solvent.

BAKING FINISHING VARNISHES.

These are similar to the baking impregnating varnishes described in the previous chapters. They invariably contain more solvent so that the film deposited by a dipped or sprayed coat is thinner and will therefore dry quicker. Additional drying agents may also be put into them.

There is no British Standard for these varnishes. They are usually tested in the same manner as the fuller-bodied impregnating varnishes of similar composition, due allowance being made for the thinner film.

AIR-DRYING FINISHING VARNISHES.

These varnishes are covered by BS. 634-1935, Finishing Air-Drying Insulating Varnish for Electrical Purposes.

The two types of varnish are recognised as follows :—

Type 1—Varnish with methylated spirit solvent.
Type 2—Varnish with non-alcoholic solvent.

Type 1 varnishes are generally composed of shellac or manilla copal gum dissolved in methylated spirit. Plasticers are often added to reduce the brittleness, and they are usually dyed black. Type 2 varnishes usually consist of bitumen in white spirit or similar solvent, or glyptal resin dissolved in xylol, suitable plasticers and dyes being added.

FINISH.

When dry, Type 1 varnish should give a hard, smooth, glossy finish on metal or insulating material. Type 2 should give a smooth finish, but it may not be as hard as that of Type 1.

VOLATILE MATTER.

This should not exceed 60 per cent for both types of varnish computed on the original weight of the varnish, the test is made in the manner described in chapter X.

SPECIFIC GRAVITY AND VISCOSITY.

These are subject to agreement between the purchaser and supplier.

DRYING TIME.

The time required for the varnish to dry in air at between 20°C. and 25°C. should not exceed :—

Type 1—Two hours.
Type 2—Six hours.

The test is made on single dipped paper as described in chapter X.

ELECTRIC STRENGTH IN DAMP ATMOSPHERE AT 20°C.

The electric strength of eight out of ten punctures should not be less than :—

Type 1—250 volts/mil.
Type 2—700 volts/mil.

The samples are prepared by giving a second dip to those used for the drying time test. They should be immersed for not more than 30 seconds, to avoid softening the first coat, and be drawn out of the varnish and suspended for drying the reverse way. When ready for test they should be not less than 5 mils and not more than 7 mils thick.

Twenty-four hours after the second coat is dry the specimens are subjected for 18 hours to a controlled atmosphere of not less than 95 per cent relative humidity (appendix C) at between 15°C. and 25°C.

The test is carried out in the controlled atmosphere at 20°C., using the electrodes and instructions in appendix D.

AGEING.

The varnish should show no sign of cracking after being tested at 40°C. (± 2°C.) for the following times :—

Type 1—Three hours.
Type 2—Six hours.

Copper foil of the thickness and quality described for the ageing test in chapter X is used for this test. A second film is floated on top of the dry first one. Care should be taken that the second application does not soften the first film. The varnish film is to be between 5 and 7 mils thick, additional coats being added if necessary, and dried. The varnished foil is next heated at 40°C. (± 2°C.), the air content being changed not less than three times per hour. Type 1 is heated for 3 hours and type 2 for 6 hours. Both types are then kept at room temperature for one hour before being tested. They should show no sign of cracking when bent in the apparatus illustrated in Fig. 27 in the manner described in chapter X.

FLASH POINT.

The closed flash point of type 2, as received, should not be less than 23°C., except by agreement. This test is made with the Abel apparatus.

RESISTANCE TO OIL.

Some machines have to run in an oily atmosphere, e.g., generators driven by Diesel engines. It is advisable to use in such cases a finishing varnish which is not affected by oil. The specification mentions that an investigation of this problem is being undertaken, but no details are given. A rough and ready test is to pour lubricating oil on a dry film on copper and rub it well with the finger. Many type 2 varnishes will soften with this treatment but type 1 are generally unaffected.

CHAPTER XIII

SHELLAC AND MICA STICKING VARNISHES

Mica sticking varnishes are of two kinds, hard and flexible. For the former shellac varnish is used almost exclusively. Until the appearance of synthetic varnishes the flexible type consisted of a suitable copal gum dissolved in spirit or drying oils.

SHELLAC.

Very few people know the origin of shellac so that a brief account will be worth while.

About 85 per cent of the world's output is produced in India, the remainder coming from other tropical countries in the east. Lac, which is the generic name of the material, is a resin or gum produced by an insect less than $\frac{1}{32}$ in. long and called *Laccifer laca.* It is the female insects which produce most of the lac. They hatch out as tiny red larvae and settle together in millions on certain trees, from which they draw sustenance by sucking the sap. This they convert into lac and waxes which are secreted and form a cell over the body. The females never leave the spot on which they settle and as the secretions grow they meet so that eventually the twigs of the trees become covered with a thick continuous or semi-continuous encrustation.

There are generally two broods in a year although one strain has three life cycles in thirteen months. The larvae leave the parent cell and swarm on to fresh parts of the trees. As successive swarming on the same trees is not good it is usual to harvest the lac by cutting off the twigs just before swarming begins. Propagation is then arranged for by tying "broodlac" (6-9 inch long lac-encrusted twigs from which the larvae have not yet emerged) to previously prepared host plants.*

The encrusted twigs not used as broodlac are known as sticklac. The lac is broken off, ground into course grains and thoroughly washed to remove foreign matter, it is then known as grain lac. After drying the grain lac is put into long tubular shaped cotton bags, melted over a charcoal fire and expressed through the walls by screwing up the bag as depicted in Fig. 28. The exuding refined lac is sometimes spread on a rotating water cooled roller from which it is removed with a knife when a thin coat has accumulated. When broken up it becomes the product which we know as shellac.

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* Extracted from "Natural Resins" B.S. Gidvani, Plastics Monograph. No. 4b.

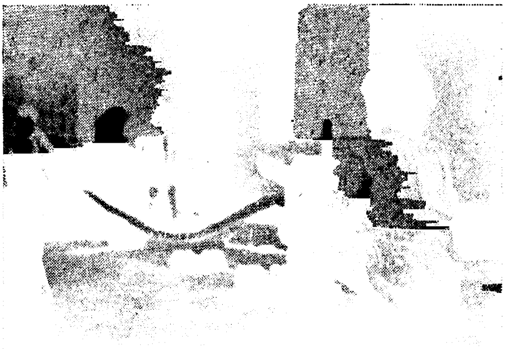

FIG. 28—Refining Lac. (By courtesy of W. F. Rhodes & Co. Ltd.)

Another method of making shellac is strikingly pictured in Fig. 29. As the lac exudes from the bag it is smeared around an earthenware vessel containing hot water. When a sufficient amount has accumulated the native removes it and stretches it into a sheet before a fire, using his hands, mouth and feet.

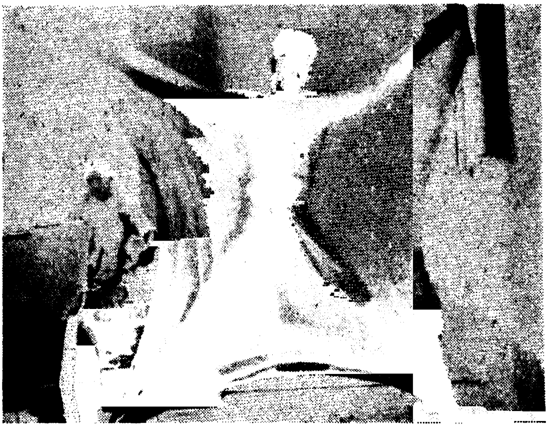

FIG. 29—Hot Lac being stretched to produce shellac. (By courtesy of W. F. Rhodes & Co. Ltd.)

Besides the well known shellac there are two other grades of lac, known as Button Lac and Garnet Lac.

BUTTON LAC is made from the hot lac as it is expressed from the tubular bag. It is made into round cakes about 3 ins. diameter. It is of the same quality as shellac.

GARNET LAC is made from dark coloured inferior grades of lac mixed with "offals" recovered from the processing of the better grades. The flakes are about $\frac{1}{8}$ in. thick—much thicker than those of shellac.

PURCHASING OF SHELLAC.

Shellac is invariably purchased against samples submitted by the seller. It is liable to be adulterated, especially with rosin. Cases have been known of shellac varnish having almost no adhesion when used for bonding mica, so that thorough tests are essential before purchasing supplies.

TESTS FOR SHELLAC.

These are covered by BS. 954-1941 for Lac. Most of the tests require special apparatus and a good training in chemistry. Such tests will not be described in detail, but the relevant figures will be given.

The specification stipulates that the natural wax shall not have been removed from the lac. Shellac shall be in "free" condition, i.e., the flakes shall not be "blocked" or adhering to one another but separable by gentle hand pressure.

FREEDOM FROM FOREIGN MATTER.

Shellac shall not contain :—

(*a*) Extraneous dirt, fibres and wood, or insect débris and other matter.

(*b*) Added organic matter, including rosin (colophony). Rosin may be detected by the Halphen-Hicks method and the quantity determined by the McIlhiney test.

(*c*) Arsenic compounds or other added colouring matter.

ASH.

The amount of ash left when about 5 grammes are burnt in a muffle furnace at 650°C. to 700°C. should not exceed 0.5 per cent computed on the weight of the "moisture-free" shellac. The ash should be free from grit as determined by examination with a low power lens after treatment with a small quantity of weak hydrochloric acid.

IODINE VALUE.

Not to exceed 18 when determined by the Wijs method.

MATTER INSOLUBLE IN SODIUM CARBONATE SOLUTION.

Not to exceed 0.5 per cent computed on the moisture free weight.

MATTER INSOLUBLE IN HOT ALCOHOL.

Not to exceed 2 per cent computed on the moisture free weight.

SOLUBILITY IN COLD ALCOHOL.

At least 92 per cent should be soluble.
For electrical purposes the lac solution shall filter readily through a BS. sieve mesh No. 72.

ACID VALUE.

Not to exceed 70 mg. of KOH per g. of lac.

VOLATILE MATTER.

As determined by loss of weight, not to exceed 2 per cent. This test is obligatory for electrical purposes and is made as follows: Grind the lac to pass through a BS. sieve mesh No. 36. Weigh 5g. into a flat-bottomed dish about 4 ins. diameter. Heat in a well ventilated oven at 41°C. (± 2°C.). Weigh the sample after 3 to 4 hours and again after a further hour's heating. If a "constant" weight has been reached, transfer to a vacuum dessicator over sulphuric acid overnight (18 hours) and weigh.

SHOP TEST.

It is not advisable to accept shellac on laboratory tests alone. A portion of the sample should be made into varnish of the specific gravity normally used and tried by using it for the ordinary shop processes.

SHELLAC VARNISH.

Shellac varnish is made by dissolving the lac in what is known as industrial spirit, which is of the same alcoholic base as methylated spirit but does not contain admixtures found in the latter. Often the basic varnish is made by using 3 lbs. of shellac to each gallon of spirit, the mixing being done in a closed wooden barrel so pivoted that the contents are well agitated as the barrel is rotated. Some people add small quantities of castor oil or Venice turpentine as a plasticiser, others do not plasticise the varnish. When the mixing is complete, the varnish is passed through a sieve and then diluted with industrial spirit to the required specific gravity, usually from 0.880 to 0.920.

Shellac varnish darkens rapidly if stored in metal containers unless they are vitreous enamelled. Earthenware storage vessels are also used.

According to recent literature good plasticisers for general purposes are methyl cyclohexanal phthalate and di-methyl glycol phthalate.[1]

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[1] *Ibid.*

FLEXIBLE MICA STICKING VARNISHES.

These are made in two types; a spirit solvent and an oil base type. The spirit type usually consists of Manila copal gum dissolved in methylated spirit with a plasticiser added. The plasticiser may be castor oil or a synthetic type such as tri cresyl phosphate or dibutyl phthalate. The oil base types are generally made of cooked Congo copal in linseed oil or other drying oil varnish to which the usual driers and solvents are added.

Each type has its special use. The spirit kind is employed as the bond in flexible micanite used between the layers in armature end windings and sometimes in making slot liners or troughs. It is not suitable for mica tape as it stiffens rather quickly and produces a harsh surface which prevents the tape from slipping and bedding properly.

The oil base type is used for the bonding of mica tape on account of its slower drying and better slipping qualities. It is not suitable for use in the comparatively thick micanite used between the layers at the ends of rotating parts since it takes a long time to dry and is liable to be flung out when machines are run for the first time. Varnish flinging does not occur from the use of oil-based varnish in the tape, since the quantity present is small and the cotton overtaping of the coils will absorb any small amount that may creep to the surface. An occasional drying test is taken on these varnishes. The dielectric strength test is not taken until it has been used in the building of flexible micanite.

CHAPTER XIV

SILICONE VARNISHES AND OTHER SILICONE PRODUCTS

Silicones are an example of pure research which has opened up a vast field of new and useful products. As has often occurred the research worker did not realise the great practical value of his discoveries. This classical research was carried out by Dr. F. S. Kipping early this century when he was Professor of Chemistry at Nottingham University.

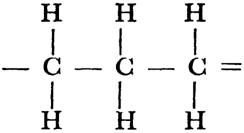
Carbon and silicon are in the same chemical group and next to one another in the periodic table, and Kipping experimented with the idea of making semi-organic compounds in which a carbon atom would be replaced by one of silicon. He succeeded in making many such compounds, but as they did not exhibit any of the properties of their hydro-carbon counterparts no use was found for them at the time.

When fibrous glass insulation had been successfully launched in the United States in the middle 1930's there became a need for impregnants which would stand higher temperatures than those then available. Research upon the subject was undertaken by the Corning Glass Works in America, the foundation having already been laid by Kipping's work. Many new and useful products were synthesised and regular production began in 1944. These products have such revolutionary prospects that some knowledge of their formulation is worth acquiring. Probably the most concise information is given in the "Westinghouse Engineer" for September, 1945, under the sub-heading "Silicone Chemistry, In Brief." It is here reproduced in full:—

> The first step in the manufacture of silicones is the conversion of sand (silicon dioxide) to silicon tetrachloride ($SiCl_4$) through the use of chlorine obtained by the electrolysis of brine. From coal and petroleum are derived several hydrocarbons, such as benzene, methane, and ethane. These are converted to chlorohydrocarbons by reaction with chlorine. One or more of these chlorinated hydrocarbons are reacted with magnesium to form a Grignard reagent which is then combined with the silicon tetrachloride. The product is magnesium chloride (akin to the original brine) and a mixture of organo-silicon chlorides. These organo-silicon chlorides have some hydro-

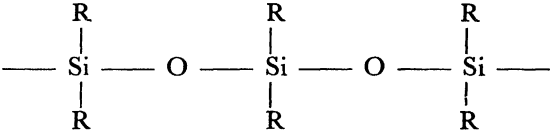
carbon bound directly to the silicon atom in place of one or more of the chlorine atoms originally attached to silicon to form silicon tetrachloride. The hydrocarbon unit may be any one of many possible ones, depending on the nature of the product sought. It may be CH_3 or C_2H_5 for example. In any case it is thought of as a unit and is termed the hydrocarbon radical, or simply R. When treated with water, the organo-silicon chlorides react to form hydrochloric acid and organo-silicon oxide condensation products known to chemists as polysiloxanes. These large molecules built upon a silicon-oxygen linkage are the units used in the molecular architecture of the silicones.

These large silicone molecular structures have approximate analogues among the hydrocarbons. But there is an important and essential difference. In the hydrocarbons each carbon atom is linked to an adjoining carbon atom, thus :—



$$\begin{array}{ccccccc} & H & & H & & H & \\ & | & & | & & | & \\ - & C & - & C & - & C & = \\ & | & & | & & | & \\ & H & & H & & H & \end{array}$$

In the silicones, however, each silicon atom is linked to an adjoining oxygen atom in this fashion :—

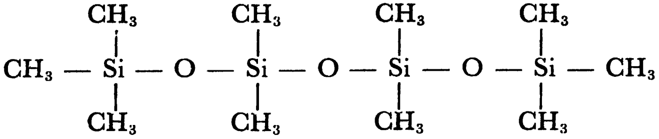


$$\begin{array}{ccccccccccc} & R & & & & R & & & & R & \\ & | & & & & | & & & & | & \\ - & Si & - & O & - & Si & - & O & - & Si & - \\ & | & & & & | & & & & | & \\ & R & & & & R & & & & R & \end{array}$$

It is this silicon-to-oxygen bond that gives the silicones some of their most valuable properties, as the accompanying text depicts.

The hydrocarbon radical is the only organic component and is bonded directly to the silicon atoms. The resulting silicone is, then, clearly neither organic nor wholly inorganic. It lies midway between the two conventional fields of chemistry and may be termed a semi-inorganic compound. There are many possible hydrocarbon radicals, but CH_3 (methyl), C_2H_5 (ethyl), and C_6H_5 (phenyl) are the more common ones. Choice of a given hydrocarbon unit from among many is one of the several variables available to the silicone molecular engineer.

Another variable in the design of a silicone is the length of the chain. This chain may be only a few silicon-oxygen-silicon links long or thousands of these organo-silicon oxide units may be linked together. Eventually, each molecule must be terminated by a blocking unit, which can be an R unit in place of an oxygen atom. The chemist can allow the molecule to grow to almost any desired length, and stop further growth by adding a blocking unit. Thus :—



$$CH_3-\underset{CH_3}{\overset{CH_3}{Si}}-O-\underset{CH_3}{\overset{CH_3}{Si}}-O-\underset{CH_3}{\overset{CH_3}{Si}}-O-\underset{CH_3}{\overset{CH_3}{Si}}-CH_3$$

Thus we have a straight-chain molecule. However, one chain can be linked to the adjoining molecule by cross links to form a three-dimensional structure. This is still another variable useful to the architect of silicone molecules.

These new reactions have yielded insulating varnishes which may be employed for bonding mica to glass fabric, for making silicone varnished glass cloth, and for the impregnation of windings. Besides being capable of working at high temperatures —say 200°C.—for an indefinitely long time, they are very resistant to moisture and have excellent electrical strength. Silicone varnished glass cloth 7 mils thick has an electric strength of not less than 1500 volts/mil.

The use of these varnishes requires new plant as one type must be baked at not less than 225°C.; another one at 150°C.

Other products include glass or asbestos boards bonded with silicones. The former are suitable for switch panels and the latter for slot wedges.

Fluids and greases which hardly change their viscosity over a very wide range of temperature are procurable in many consistencies.

A rubber-like product has also been produced. It has not the tensile strength of natural rubber but is especially suitable for gaskets to work in temperatures which would destroy natural rubber or cork. It is oil resistant.

There are also silicone paints for use on high temperature apparatus.

PERFORMANCE OF SILICONE INSULATED MOTORS.

American technical literature contains test figures of a number of silicone insulated motors. When compared with the temperatures at which class B insulated machines are allowed to run those for silicones appear fantastic. Running temperatures of 250°C., and even 300°C. are frequently quoted.

It may be stated right away that sufficient experience has now been obtained here to confirm that silicones will do all that are claimed for them. The following account of the behaviour of a motor under test in the laboratory at the works with which the author is associated will be of particular interest. Although only a small machine the results are such as to give one confidence in the use of silicones in larger ones.

The motor is nominally of 1 h.p., 440 volts, 3 phase, with squirrel cage rotor, the mechanical construction being entirely standard. The stator winding is of glass covered wire impregnated with DC993* silicone varnish; the slot liners are of 5 mil mica-glass bonded with DC993 varnish and the end windings are insulated with silicone impregnated glass tape. The wedges are of silicone bonded asbestos paper board. The completely wound stator was impregnated twice by immersion in DC996 silicone varnish, which bakes at 150°C. whereas DC993 requires 225°C. A thermocouple was put in one slot.

For the greater part of sixteen weeks the motor was run on load for 5 days in each week giving nearly double the normal output and working at temperatures between 250°C. and 300°C. in the slots. It was shut down each night and week-end so as to permit of frequent large temperature changes.

On several occasions the motor was subjected to an atmosphere of 95 per cent relative humidity for 48 hours after which the insulation resistance was never less than 50 megohms. At another time it was given five tropical cycles consisting of 8 hours at 60°C. and 98 per cent relative humidity followed by 16 hours cooling in the chamber, during which liberal condensation occurred. At the end of the fifth cycle the I.R. had fallen only to 20 megohms. The motor was always put back on load runs as soon as removed from moist atmospheres, no time being allowed for drying out.

At the end of twenty weeks the stator was completely immersed in water for 48 hours. It was then allowed to stand in the air and was put back on load as soon as the insulation resistance showed signs of rising.

When this account was written the motor had been running for six months and still showed no sign of electrical failure in spite of the rough treatment. As would be expected, bearing failures have occurred, since no attempts were made to prevent the great heat generated from reaching them. Bearings lubricated with normal greases failed quickly. The use of silicone greases was very beneficial, but did not prevent occasional failures.

USES FOR SILICONE INSULATED MOTORS.

At the present time silicones are scarce and very expensive, for which reasons their use is rather restricted. This condition need not prevent consideration of what may happen when they are more plentiful and prices fall, as they may do in due course.

It is probable that traction motors, aircraft motors and generators, and rolling mill motors will be the first types to make use of silicones. Since traction motors are carried about by the vehicles they drive it is desirable to cut down their weight as much as possible. This can only be done by running smaller motors at higher temperatures. Higher temperatures are accompanied by lower efficiency, and some compromise may be necessary whereby the motors are run at a temperature that is intermediate between the present figures and the maximum considered safe for silicones. Temperatures of between 150°C. and 200°C. seem probable.

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* DC stands for Dow-Corning Corporation of America.

The use of higher temperatures will doubtless necessitate some changes in design. In most cases the bearings will have to be protected from the heat. Although a grease may be found which will work satisfactorily for a long time, too high a temperature will not be good for the hardness of the balls and races. With D.C. machines new methods of making the commutator joints may be essential as well as a means of keeping the commutator cool.

High temperature motors are not needed in rolling mills because of the necessity to reduce their size. The difficulty is that hot billets or pieces may at times be dumped near motors and so cause dangerous temperatures. The extra safety provided by silicones will be useful in such cases.

Motors for driving machine tools have sometimes to be crowded into confined spaces on the machines. The provision of smaller motors by employing silicones may prove advantageous.

Generally speaking high temperature motors will not be needed in the vast majority of cases, but there are instances where the extra protection against moisture offered by silicones will prove attractive. Many motors essential to the running of a ship come within this category, and so do many motors for mines.

So far as ordinary industrial machines are concerned, there are no serious reasons why anything more expensive than the present types should be used. Generally there is always ample room and therefore no need to put up temperatures and reduce sizes, neither is there a strong case for greater reliability since the percentage of failures of machines made by reputable firms is extremely small.

The time may come when glass becomes cheaper than cotton, and silicone varnishes and other products become competitive with what are now looked upon as normal media. When this happens the revolution will come about in a natural way.

In the meantime, and for the first time in the history of the electrical industry, it can be said that what limits the temperature at which machines can be run is not the insulation, but what is safe for the proper functioning of the magnetic circuit and the mechanical parts.

CHAPTER XV

VARNISHED FABRICS AND TAPES OF VARIOUS KINDS

In this chapter consideration is given to the manufacture of varnished cotton cloth, silk (or rayon), fibrous glass, and the testing of these materials and the tapes slit from them. The varnished cotton and silk fabrics are often known as empire cloth and empire silk.

It will perhaps not be out of place to reiterate what has been said in chapter X about raw fibrous materials—silk, rayon, cotton, paper, etc.—not being very good as insulators. They hold moisture and are full of air spaces which break down at comparatively low voltages. It is the medium, such as varnish, bitumen, oil or wax, with which they are impregnated which is the real insulator; the fibrous material is merely a carrier for the insulating medium.

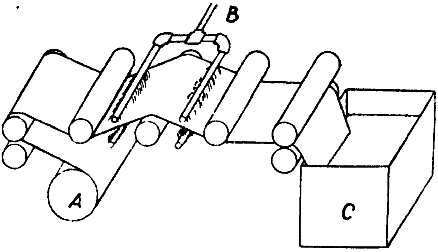


FIG. 30—" Gassing " of cloth.

COTTON CLOTH AND ITS PREPARATION.

Cotton is the seed hairs of the cotton plant. We cannot deal with the manufacture of cotton cloth from the raw cotton, but it is desirable that one should learn something about the processes applied to manufactured cloths to render them suitable for use in the electrical industry.

The woven cloth undergoes a lengthy treatment before it is ready for varnishing. First, the knap or hairs protruding from the surface must be removed because if the varnish film is punctured by them, moisture is liable to enter, with consequent deterioration of the dielectric strength.

This process is known as "gassing" the cloth and is shown diagrammatically in Fig. 30 where A is the roll of cloth, B gas jets and C a tank of water into which the cloth is passed to avoid fire. After this the cloth is boiled for about a week in frequent changes of water; this is done to remove the natural waxes in the cotton and any sizes used to give strength to the yarn for weaving. It is next starched with pure starch to fill in the interstices between the threads, and to lay any remaining hairs. It is then calendered between heated polished steel rolls to give it smooth surfaces and uniform thickness.

APPLYING THE VARNISH TO ALL TYPES OF FABRIC.

A photograph of the equipment for varnishing various kinds of cloth is shown in Fig. 31. The varnish is contained in a tank on the floor under each tower. A roll of untreated silk fabric is shown on the machine at the left forefront; from there it passes under a roll in the varnish trough, up the tower, over a roll at the top and then comes out and is rolled up with waxed paper. The machine numbered 23 on the right shows varnished cloth being rolled up. The waxed paper is wider than the cloth. An oil base varnish, with bitumen incorporated for black cloths, is employed. Very careful control of temperature, speed and the viscosity of the varnish is essential to ensure uniformity of the product. The cloth, depending upon the thickness required, receives one or more coats of varnish in this manner.

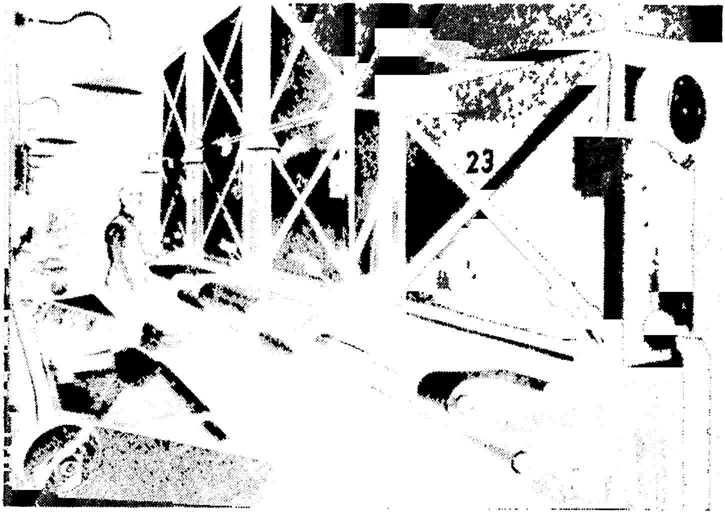


FIG 31—Towers for the production of varnished fabrics. (H. D. Symons Ltd.)

Glass cloth is coated in the same manner, but is first prepared by passing through a gas flame to burn off the lubricant added to the yarn at the time of manufacture. Synthetic varnishes which will stand higher temperatures are employed in place of those used for cotton and silk.

DIMENSIONS OF VARNISHED FABRICS.

These are obtainable in rolls of 36 or 50 yards and in the following thicknesses:—

Varnished cotton—5, 7, 10, 12, 15 mils.
Varnished silk (or rayon)—3, 4, 5, 6 mils.
Varnished glass (on 2 mil fabric)—3, 4, 5, 6 mils.
Varnished glass (on thicker fabrics)—5, 7, 10, 12, 15 mils.

Varnished cotton fabric is supplied in three forms; straight woven, sewn bias cut, and seamless bias.

The two drawings of Fig. 32 show how the cloth is manipulated for making sewn bias material. It is cut along the sloping lines, which are 36 ins. apart, and the pieces are then turned so that the parallel lines representing the edges become the diagonals, as shown in the bottom diagram. The pieces are sewn together to form long lengths before being varnished. Cloth fabricated in this manner and tape slit from it, will have a join about every 50 ins.

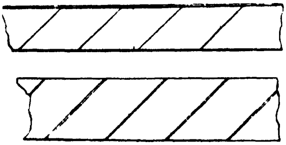


FIG. 32—Method of preparing cloth for making sewn bias tape.

Seamless bias cloth is obtained by weaving the material in tubular form and then slitting it spirally so that when opened out it gives a cloth 36 ins. wide with all the threads making an angle of about 35 degrees with the edge. Theoretically the angle should be 45 degrees, but the operations subsequent to slitting result in the angle of weave being altered.

Silk is always varnished in the straight woven condition at the outset. It is possible to cut it into bias lengths after the first coat of varnish, and sew the lengths together, but manufacturers do not recommend this.

Fibre glass can only be obtained in the straight woven condition at present. It is not possible to sew bias cut pieces together. It has recently been woven in the tubular form from which seamless bias fabric is cut, so that seamless bias varnished fabric is now a possibility, although its manufacture will present some new problems.

It is quite unnecessary to use all the thicknesses of fabric listed above. For general purposes 5 and 7 mil cotton, 4 mil silk, 4 and 8 mil glass will suffice. Those thicknesses not needed for machines are used in other branches of the electrical industry.

Varnished Fabric Tapes.

These are slit from the varnished cloths just described. Thus varnished cotton products of 5, 7 and 10 mils thickness. There cut, sewn bias cut and seamless bias cut. Continuous lengths of varnished silk and glass tapes can only be provided in the straight cut variety. If they are required bias cut it is usual to supply lengths of about 50 ins. made up into rolls with waxed paper interleaving. The length in a reel, which is the name given in BS. 419-1931 to rolls under 6 ins. wide is 36 or 50 yards.
The most useful sizes are:—

Varnished cotton—5 mils $\frac{1}{2}$ in. wide; 7 mils $\frac{1}{2}$, $\frac{5}{8}$, $\frac{3}{4}$, 1 in. wide.
Varnished silk—4 mils, $\frac{3}{8}$, $\frac{1}{2}$ in. wide.
Varnished glass—4 mils $\frac{1}{2}$, $\frac{5}{8}$, in.; 8 mils.

Eight mil varnished glass tape is useful for interleaving between the turns of bare strip-on-flat interpole or field coils and the widths must be ordered specially for the purpose.

The straight cut tape being slit from rolls of varnished cloth has the same tensile strength per inch width as the cloth. Whilst this type is satisfactory when taping straight bars or applying to the smooth outside perimeter of coils, it is not very suitable for taping the ends or noses of diamond shaped stator coils, or the corners of field coils. It has not much flexibility and does not lie snugly when applied to curves in two planes. For these reasons bias tapes are generally employed.

In bias tapes all the threads make an angle of 35 degrees with the edges and this gives the tapes much more flexibility. With this tape none of the threads are in a direct line with the pull that is applied during taping and an appreciable proportion of the tension is taken by the varnish film. More care has therefore to be exercised when using this tape because if the varnish film is stretched much its dielectric strength is reduced.

There are many instances where the joins in sewn bias tapes are objectionable. If the tape were used on the slot portions of coils the extra thickness would probably prevent the coils entering the slots. In high-voltage windings, where many layers of tape are used, they would produce air pockets in which corona might occur. Whilst the joins can be cut out during the process of taping, the operation takes time, and an extra thickness of tape results because of the overlapping when joining in again. This extra thickness may prevent coils from entering slots since it increases the overall width. The use of seamless bias tape obviates these troubles.

Varnished cotton tapes can be procured with a coloured line down the centre. Besides having a different coloured line to indicate the thickness, there are other advantages. These are discussed in chapter XXI.

TESTING VARNISHED FABRICS AND TAPES.

British Standard No. 419-1931, Varnished Cloth Sheet, Strip or Tape for Electrical Purposes (Excluding Cables) covers varnished cotton products of 5, 7 and 10 mil thickness. There are no British Standards for varnished silk or glass fabric, but difficulty should not arise in deciding upon suitable tests after studying the following review of BS. 419. Figures by which to judge the performance of the other fabrics and tapes will be given after dealing with the tests for varnished cotton products.

In BS. 419 it is stated that black varnished cloth and tape are superior to the yellow in several respects. The surface is rather more slippery, it is more flexible, the dielectric strength is somewhat higher, and it does not deteriorate so rapidly under tropical conditions or in the presence of chemical fumes in the atmosphere. The yellow material will withstand immersion in hot oil better and has greater resistance to crushing and abrasion.

The surface of the varnished cloth should be uniform, reasonably smooth and free from defects such as bubbles, pin holes, creases and flaws. The material should be capable of being unrolled without damage.

THICKNESS AND WIDTH.

Thickness is always measured with the material in the free state, taking not less than four thicknesses together, and employing a ratchet micrometer having an anvil and spindle of not less than $\frac{3}{8}$ ins. or more than $\frac{1}{2}$ in.

The tolerance on thickness should not exceed that given in Table 11.

Table 11.—Tolerance on Thickness of Varnished Cotton Cloth and Tape.

Nominal Thickness	Tolerance
mils.	Per Cent.
5	— 0 + 20
7	— 10 + 10
10	— 10 + 10

The tolerance on the width of cloth nominally 36 ins. wide should not exceed ± 1 inch. For widths less than 36 ins. down to and including 6 ins. the tolerance is by agreement.

For strip or tape up to 6 ins. wide the tolerance should not exceed ± $\frac{1}{64}$ in.

LENGTH AND JOINS.

The length of cloth or tape in a roll may be 36, 50, or 72 yards or more ± 1 yard. There shall be no joins in straight cut cloth or tape in rolls of any of these lengths. In sewn bias-cut material the length between any two joins is not to be less than 48 ins. Sewn joins in tape should have a tensile strength not less than twice the appropriate load given in Tables 13 and 14.

CONDITIONS FOR ACCEPTANCE OF MATERIALS.

In the following tests taken from BS. 419 it is stipulated in the specification that the material shall be deemed to comply with the requirements if it passes not less than four out of five tests in appropriate sections.

ELECTRIC STRENGTH.

There are two methods of applying the voltage :—

(*a*) It may be raised quickly so that puncture occurs in about ten seconds; this is known as the instantaneous value.

(*b*) It may be raised to a definite value and the specimen must stand this voltage for one minute without failure; this is known as a one-minute proof stress test.

Figures for proof stress tests are given in BS. 419 and are reproduced below. Instantaneous test figures will be given later.

ELECTRIC STRENGTH OF CLOTH AND TAPE AT 90°C.

The cloth should stand for one minute the appropriate voltage given in Table 12, the voltage being increased at a uniform rate from zero to the test figure in about 10 seconds.

Table 12.—Electric Strength at 90°C. (One Minute Proof Stress).

Nominal Thickness	Volts per Mil			
	Yellow Varnish		Black Varnish	
Mils	Large Electrodes	Small Electrodes	Large Electrodes	Small Electrodes
5	450	550	600	700
7	500	650	650	750
10 .	550	700	650	750

The electrodes are heated at 90°C. (± 2°C.) before being put into contact with the specimens.

Tape which is not narrower than ¾ in. may be tested at 90°C. by using the apparatus described below. For this test straight-cut tape is not put in tension. The apparatus is heated to 90°C., the temperature being checked by placing a thermometer in one of the holes. The figures given in Table 12 apply to tapes tested in this manner.

ELECTRIC STRENGTH OF BIAS-CUT TAPE UNDER MECHANICAL TENSION AT 20°C.

A. *Tapes not less than ¾ in. wide.*

Samples should withstand for 1 minute without failure the appropriate voltage computed from Table 13 when under the tension specified in that table. The test should be carried out at 20°C. (± 5°C.). Before testing the specimens are conditioned for 18 hours in a controlled atmosphere of 75 per cent relative humidity (Appendix B) at 20°C. to 25°C. The specimens should be not less than 18 ins. long.

Table 13.—Electric Strength of Bias Cut Strip or Tape (¾ inch and wider) under Mechanical Tension at 20°C. (One Minute Proof Stress).

Nominal Thickness	Load	Volts per Mil Yellow Varnish	Volts per Mil Black Varnish
Mils	Pounds per inch width	Small Electrode	Small Electrode
5	3	700	750
7	4	750	800
10	5	800	850

Details of the apparatus are shown in Fig. 33. It consists essentially of two wooden blocks 9 in. long with electrodes and a means of applying tension to the tape. There are five ½ in. electrodes in the base in line with the holes in the top block; these five are connected together and to the earthed side of the high voltage supply. The electrode shown in one of the holes is used in each hole in succession so that five tests are made on each specimen.

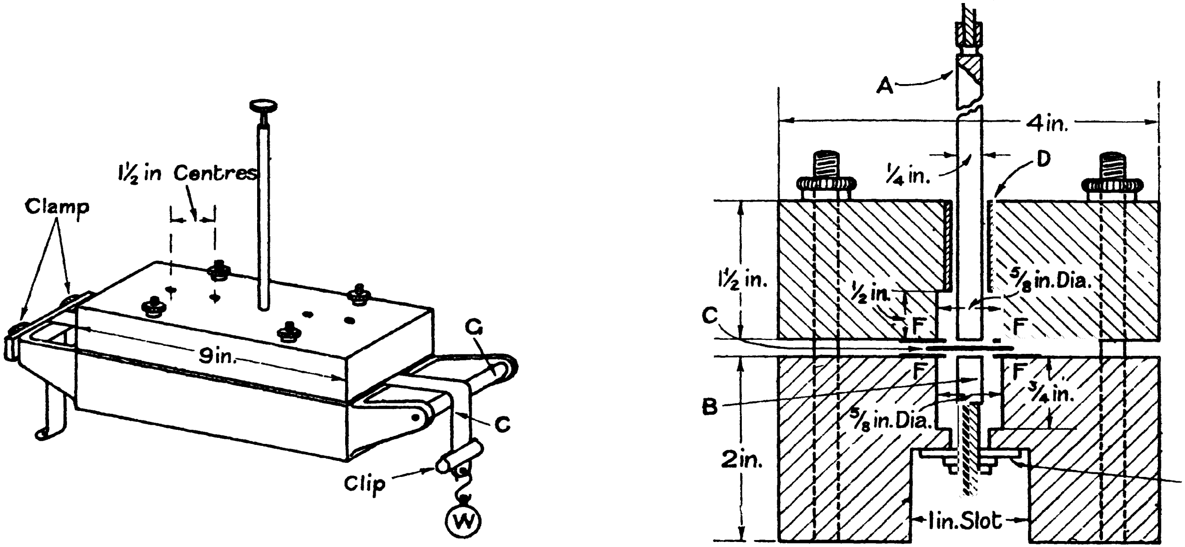
To prevent flash-over round the sample strips of varnished cloth are placed along the length of the apparatus on both the upper and lower blocks, their inner edges running close to, but not touching the electrodes. The sample under test is clamped between these strips.

If the electrodes become pitted they should be turned up in a lathe in order to maintain the specified rounding of the edges. Tape or strip which is too wide to go into the apparatus should be reduced so that it will do so.

B. *Tapes less than ¾ in. wide.*

These should withstand for 1 minute without failure the appropriate voltage given in Table 14. They should be conditioned as in (A) above, and the test is made at 20°C. (± 5°C.).

Tapes narrower than ¾ in. are wound spirally on to a steel rod ½ in. dia. using the apparatus depicted in Fig. 34 to ensure the correct pitch of the spiral. The inclination of the rod with the horizontal varies with the width of the tape and is 15°, 16½°



(*a*) Apparatus with sample set up for test under mechanical tension.

(*b*) Section of apparatus through electrodes with top slightly raised.

A. Upper electrode. To be an easy fit in bush D.
B. Lower electrode.
C. Sample under test.
D. Brass bush. Inside diameter just sufficient to clear ¼ inch rod.
E. Brass strip 1 inch wide connecting all lower electrodes.
F. Pieces of varnished cloth strip overlapping edges of sample.
G. Roller ⅜ inch diameter. Free to revolve.

FIG. 33—Apparatus for checking electric strength of varnished tapes not less than ¾in. wide.

Table 14.—Electric Strength of Bias Cut Strip or Tape less than ¾ inch wide under Mechanical Tension at 20°C. (One Minute Proof Stress).

Nominal Thickness	Load	Volts per Mil	Volts per Mil
Mils	Pounds per inch width	Yellow Varnish	Black Varnish
5	4	550	600
7	5	550	600
10	6	550	600

and 18° for tape widths of ½ in., ⅝ in. and ¾ in., respectively. These angles produce an overlap and leave a single thickness helix of tape ⅛ in. wide. The taped rod is removed from the winding fixture and tested by fitting a split, spring-controlled, electrode 1 in. long over the outside.

It is sometimes found that whilst tapes pass these tests at 20°C. they will stretch so much at 25°C. that the electric strength falls below the permitted figures.

Straight-cut tapes will not stretch appreciably at the loads specified in Table 13. No guidance is given for the testing of this type. A test at 90°C. seems to be the most suitable.

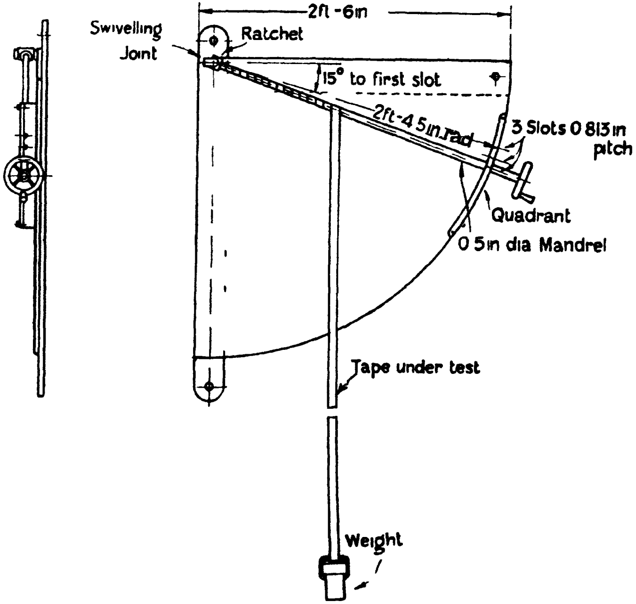
TENSILE STRENGTH.

This should not be less than the appropriate figures given in Table 15.

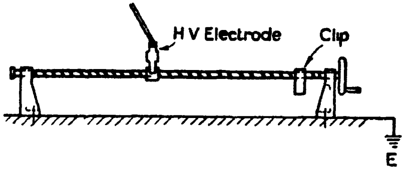
Table 15.—Tensile Strength of Cloth and Tape.

NOMINAL THICKNESS	MINIMUM TENSILE STRENGTH					
	YELLOW VARNISH			BLACK VARNISH		
	Straight Cut		Bias Cut	Straight Cut		Bias Cut
	Warp	Weft		Warp	Weft	
Mils	lb. per Inch Width	lb. per Inch Width	lb. per Inch Width	lb. per Inch Width	lb. per Inch Width	lb. per Inch Widt
5	25	15	15	25	15	15
7	30	20	20	30	20	20
10	35	25	25	35	25	25

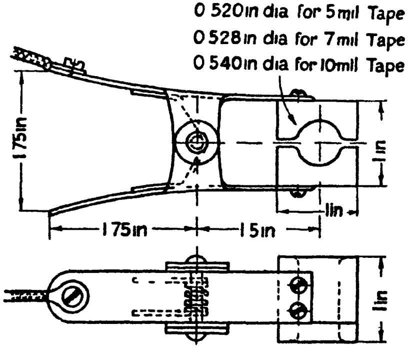
In the case of cloth, ten specimens 2 ins. wide are cut from the warp direction and ten from the weft direction. They are cut of such a length that the unstretched length between the jaws of the testing machine is not less than 6 ins. The apparatus



(a) Apparatus for winding the tape onto the mandrel



(b) Rod removed from winding apparatus and mounted for application of voltage test


0 520in dia for 5mil Tape
0 528in dia for 7mil Tape
0 540in dia for 10mil Tape
1 75in
1in
1in
1 75in
1 5in
1in

(c) High voltage electrode

FIG 34—Apparatus for checking electric strength of varnished tapes less than ¾in wide

depicted in Fig. 17 (p. 39) is useful for testing tapes not wider than 1 in.

Before the test the specimens are conditioned as for the electric strength test at 20°C.

Tearing Strength.

The tearing strength should not be less than the values shown in Table 16.

Table 16.—Tearing Strength of Varnished Cotton Cloth.

	TEARING STRENGTH (DOUBLE TEAR)			
Nominal Thickness	Warp Tear (i.e., Travel of Tongue Parallel to Selvedge Across Weft Threads		Weft Tear (i.e., Travel of Tongue Parallel to Weft Threads	
	Yellow Varn.	Black Varn.	Yellow Varn.	Black Varn.
Mils	Ounces	Ounces	Ounces	Ounces
5	14	14	18	18
7	14	14	18	18
10	16	16	20	20

The specimens are conditioned as before for this test, which is carried out at any temperature between 15°C. and 25°C.

The resistance to tearing is determined by the load required to tear a tongue 2 ins. wide commencing from the two $\frac{3}{32}$ in. holes shown in the diagram Fig. 18 (p. 40). It will be seen that the tongue cut out along the dotted lines is attached to the mechanism for applying the load. The load is applied so that tearing proceeds at a uniform rate of about 12 ins./min. The readings of the spring balance are observed for the first 2 ins. of the tear, and the average of all the varying peak values is taken to be the tearing strength.

Instantaneous Breakdown Values.

This term implies that the applied voltage is increased from zero at such a rate that puncture takes place in about 10 seconds. Higher voltages are specified for these tests than for proof tests of the type just discussed.

Some people prefer instantaneous tests for routine checks and the values given in Tables 17 and 18 will serve as a guide to the figures normally obtained from these tests. They are not covered in BS. 419.

Varnished Fabrics and Tapes in the Tropics.

It was found long ago that varnished cloths and tapes were adversely affected if stored in the tropics. The varnish would become soft and sticky so that rolls could not be unwound. This would happen after about one year's storage, unless they were

Table 17.—Instantaneous Breakdown of Varnished Fabric Tested with Large Electrodes at 90°C. Volts/mil.

Thickness, mils ...	3	4	5	7	10
Yellow Varn. Cotton	–	–	1000	1000	950
Black Varn. Cotton	–	–	1100	1100	1100
Varnished Glass ...	1020	900	800	600	450
Varnished Silk ...	1190	1450	1490	–	–

Table 18.—Instantaneous Breakdown of Bias Cut Varnished Tapes under Tension at 20°C. Volts/Mil ¼ inch diam. Electrodes.

Thickness, mils ...	3	4	5	7	10
Yellow Varn. Cotton	–	–	–	900*	–
Black Varn. Cotton	–	–	1000‡	1000†	–
Varnished Glass§ ...	1750	1300	970	1100	1000
Varnished Silk§ ...	2400	2500	2200	–	–

* When under a Tension of 7 lbs./inch width.
† When under a Tension of 6 lbs./inch width.
‡ When under a Tension of 3 lbs./inch width.
§ When under a Tension to give 10 per cent. increase in length.

hermetically sealed, in which case they might remain good for two or three years. Machines insulated with these materials and sent abroad have given satisfactory service, probably because the extra heat generated has prevented the moisture from seriously affecting the material.

A test for the reliability of these materials in the tropics has been devised.* Since it is the varnish, not the carrier, which fails, this test is applicable to all types of varnished fabrics and tapes, papers and sleevings.

A piece of the material weighing 2 grammes is rolled up and placed in the bottom of a 5 ins. × ½ in. test tube. If it does not unroll and wedge itself it should be fixed in such a way that it will remain at that end of the tube when it is subsequently turned upside down. Two cu. cm. of distilled water are put into the tube which is then hermetically sealed.

The tube is placed vertically in an oven so that the material is at the top and the water at the bottom. It is heated at 110°C. until the varnish begins to flow down the tube. In general this will occur in 60 to 70 hours with yellow varnish, and in 100 to 140 hours with black varnishes. A varnish which does not commence to flow until after 100 hours will probably be satisfactory for the tropics, even without being hermetically sealed.

* Developed in the Laboratory of H. D. Symons Ltd.

CHAPTER XVI

IMPREGNATING COMPOUNDS

These substances are used for the impregnation of field coils, small wound stators for A.C. motors, and stator coils for large machines such as turbo-alternators.

BITUMEN AND COMPOUND.

These two words are often used indiscriminately and in American technical literature the medium is frequently spoken of as "gum." It is perhaps more correct to apply the name "bitumen" to substances found in nature and "compound" to those which are derived from the distillation of crude oil and blended with other compatible substances.

It is thought that bitumen came originally from crude oil but how the change occurred is uncertain. The origin of the oil is also a matter for speculation. Geologists are generally of the opinion that it came from the decomposition of vast deposits of organic matter which accumulated in stagnant sea bottoms in early geological ages. Whether these deposits were of microscopic plants or animals is still a matter of speculation.

Bitumen is found in many consistencies in nature. In the famous lake in Trinidad it is soft and is dug out with spades. In other places it is hard and brittle. In such cases it is in veins in the earth varying from a few inches to many feet in thickness, and is either quarried or mined. Of this type, two kinds found in Utah are used in the manufacture of insulating varnishes. They are known as Gilsonite and Manjak or Glance Pitch. Although the softer types are much used for filling cable troughs, they are not employed for machines.

PRODUCTION OF BITUMENS FROM CRUDE OIL.

Practically all the so-called bitumens used for the impregnation of coils are derived from the distillation of crude oil and are blended to form compounds. Since crude oil varies, great care is taken in its selection, it being customary for distillers to obtain their crudes from the same area to ensure a continued uniformity of by-products. The crude oil must be selected to yield a bituminous residue having definite characteristics. Elaborate precautions must be taken throughout the whole process of distillation, to exclude accidental or other ingress of harmful substances. The full distillation process is very complex and will yield approximately 5 per cent of petrol, 5 to 10 per cent of heavier petroleums such as white spirit and paraffin, 30 per cent diesel oil, 5 to 10 per cent light lubricating oils, a similar quantity of heavy lubricating oils, and about 45 per cent of bitumen. The petrol and white spirit are removed by preliminary distillation at comparatively low temperature. Extraction of the other fractions is often carried out in the presence of superheated steam in the early stages, and under vacuum for the later stages.

Blown Bitumens.

Bitumens produced in the above manner, although they may appear solid, are in fact, liquids of extremely high viscosity. They will ooze very slowly through quite small holes in their containing vessels. However, by heating them strongly and bubbling air through them, it is possible to raise their softening point and modify their plastic range. By suitable control of the process, the bitumen will stand higher temperatures without flow under gravity, and yet not be brittle when cold. These are known as blown bitumens.

Further modifications in characteristics are produced by introducing organic substances which are soluble in molten bitumen. Colophony, mineral and vegetable waxes, alochlor and aloprene are some of the substances used for the purpose.

Types of Compound for Various Applications.

Broadly speaking three classes of compound are used for the impregnation of field coils and each is equally satisfactory if suited to the occasion. Compounds having a dropping or softening point in the region of 55°C. (Class II BS. 688) are eminently suitable for coils which are not taped all over. They penetrate well and are so fluid at the impregnating temperature that all excess compound readily drains away during the draining period, this avoiding " bleeding " when the coils are in service. Unless all superfluous compound is removed, it is likely to seep into the air gap of a machine and lock the armature when it is cold. Many years' experience prove that such coils are perfectly reliable in every respect.

The second type, which complies with Class IV in BS. 688, has a dropping point of about 95°C. This tends to cling to the cotton covering on the wire and to remain in the interstices in the winding. Compounds of this type are semi-fluid at temperatures below their dropping point and will slowly ooze out of coils in service if not prevented from doing so by taping the coils all over. The insulation to earth and overall taping are put on before the coils are impregnated and have the effect of retarding penetration; this, combined with the lesser fluidity of the compound at the impregnating temperature, often results in the inside of coils which are more than about 2 in. thick, remaining unimpregnated. However, long experience has proved that such coils are quite satisfactory.

For coils which are subject to short periods of very high temperature, such as those in traction motors, a class V compound with a dropping point of not less than 120°C. is often used. Such coils are invariably taped all over. This type of compound does not drain off the outer surfaces and leave them smooth and it is customary to put on an additional layer of cheap tape having a very open weave. This outer tape is known as stripping or sacrifice tape and is removed after the impregnating process so as to leave the coils with smooth surfaces.

Class IV compound is generally used for the impregnation of stator coils and small wound stators.

SPECIFICATION AND TESTS.

These are covered by BS. 688-1936, Bituminous Filling Compounds for Electrical Apparatus.

CLASSIFICATION.

Five classes are defined, of which three have already been mentioned. The five classes are :—

Class

I. Fluid grade. Softening point less than 40°C.

II. Plastic grade. Softening point less than 70°C. but excluding Class I.

III. Medium-hard grade. Softening point not below 70°C. and less than 90°C.

IV. Hard grade. Softening point not below 90°C. and less than 120°C.

V. Extra-hard grade. Softening point not below 120°C.

GENERAL PROPERTIES.

The specification stipulates that the compound must be capable of being re-melted repeatedly without separation of the constituents and must not form gas pockets or cracks on cooling. It must be stable and have no injurious effect on fibrous materials such as cotton, paper and the like, nor on copper, brass or iron at the service temperature.

SOFTENING POINT.

Compounds are not purchased simply as belonging to a certain classification since the range of softening point temperatures is much too wide. A definite softening point temperature is agreed with the supplier and the compound must not differ from it by more than ± 3°C. for grades II, III and IV, and ± 4°C. for grade V. It is not intended that the softening point of Class I compound should be determined; a viscosity test is better in this case.

The softening or dropping point test is the most frequently applied test. The essential features of the apparatus are shown in Fig. 35. Molten compound, heated to not more than 100°C. above the approximate softening point and stirred thoroughly, is poured into the brass ring A, as it rests on an amalgamated brass plate. It is allowed to cool in air for half an hour, after which the top surface is smoothed off with a warm knife.

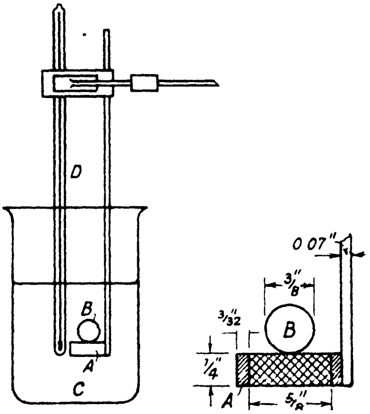


FIG. 35—Apparatus for determination of softening point of bitumen.

When testing compounds having a melting point not exceeding 80°C., distilled water is used in the beaker. For higher melting point compounds glycerine is used. The surface of the liquid is to be exactly 2 ins. above the upper surface of the filled ring, the lower surface of which should be exactly 1 in. above the bottom of the vessel.

Heat is applied to the bottom of the beaker in such a manner that the temperature of the liquid rises 5°C. each minute. It is important that this rate of rise should be uniform throughout the test, and not arrived at by averaging over the whole time. The maximum permissible variation for each minute period after the first three is ± 0.5°C.

The circle B. in Fig. 35 is a steel ball ⅜ in. diameter weighing between 3.45 and 3.55 grammes. The temperature recorded by the thermometer at the instant the sample surrounding the steel ball touches the bottom of the glass vessel is taken as the softening point.

ELECTRIC STRENGTH (PROOF TEST).

This test is carried out in the apparatus depicted in Fig. 36. The compound should withstand for 1 minute without puncture

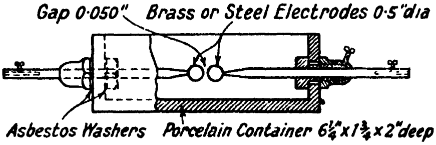

Gap 0·050"
Brass or Steel Electrodes 0·5"dia
Asbestos Washers
Porcelain Container 6¼"x1¾x2"deep

FIG. 36—Apparatus for electric strength (Proof Test) of bitumen.

the appropriate voltage given in Table 19. The table also states the temperature at which the test should be made. Owing to inherent difficulties in making the test, the compound is considered to comply with the requirements if two out of three successive tests are passed.

Table 19.—Electric Strength (Proof Test) of Bitumen.

Class of Compound	Test Temperature °C.	Softening Point of Compound °C.	Pouring Temperature above Softening Point °C.	Test Voltage Volts.
I	60 ± 1	Below 70	75	10000
II	60 ± 1	Below 70	75	20000
III	60 ± 1	70 to 90	80	20000
IV	90 ± 1	Above 90	90	20000
V	90 ± 1	Above 90	90	20000

Before being poured into the apparatus the compound and apparatus should be heated to the appropriate temperature in Table 19. They are allowed to cool to the testing temperature in the table and are maintained at that temperature for one hour before the test is made. The depth of compound above the electrodes must be at least 1 inch.

Since the distance between the electrodes must be correct at the test temperature, it is advisable to set the gap at the appropriate temperature whilst the apparatus is being heated up.

The test voltage should be alternating, of approximately sine-wave form with a peak value not more than 1.45 times the R.M.S. value. The frequency may be any convenient value between 25 and 100 periods per second.

OTHER TESTS.

Other tests are of a chemical nature requiring special apparatus and a training in chemistry. They will not be described, but the conditions to be met are given. Unless otherwise stated the figures apply to all classes.

(*a*) The insoluble content in carbon disulphide not to exceed 0.5 per cent.

(*b*) When completely ignited the mineral ash not to exceed 0.5 per cent.

(*c*) The amount of acid per gramme of compound not to exceed that required to neutralise 4 mgm. of potassium hydroxide.

(*d*) Freshly polished copper foil immersed in a warm solution of 1 gm. of compound in 50 ml. of solvent (*e.g.*, chloroform, carbon tetrachloride, methylene chloride) for half an hour not to be appreciably blackened.

CHAPTER XVII

MICA AND MICA COMPOSITIONS

Mica is the most useful electrical insulation known. If it were not for this material it is doubtful whether the electrical industry would have reached the pre-eminent position it holds to-day. It would be difficult to imagine that large turbo alternators for 11 kV, or more, could have been produced with varnished paper or cloth as the sole insulation.

CLASSIFICATION OF MICA.

There are four chief classes of mica, but only two of them are suitable for electrical work. The one used almost exclusively in this country is known as Muscovite or Potassium mica. Practically all of the supplies come from the provinces of Bengal, Madras and Rajputana in India. It is found in other parts of the world, but the cost of mining it is too great.

The other type is known as Phlogopite or Magnesium mica. In the electrical industry the familiar name is amber mica. The chief sources of supply are Madagascar and Canada. It is softer than Indian mica and in consequence is sometimes used for small commutators in which the micas are not undercut as it wears away at the same rate as the copper.

FIG. 37—View of a typical mica quarry.

Mica is a natural mineral and occurs in veins of varying thickness. Sometimes it is obtained from open quarries, as illustrated in Fig. 37, and in other cases it is obtained from mines deep in hillsides or underground. The pieces of crude mica vary from small fragments to large pieces a square foot or more in area and several inches thick. Some blocks contain many impurities and the mica from these is used for less exacting duties than those demanded for machines.

Indian mica varies in colour and it is often described by this means. Thus we hear of ruby, green and clear mica. It is mainly purchased in the form of splittings—one of the peculiarities, and a most useful property of mica, is that it can readily be split into laminae about .001 in. thick. In thin splittings the colour is seldom evident, but if about a dozen are put together and held up to the light the distinctive colour becomes noticeable.

CHOOSING MICA SPLITTINGS—FLEXIBILITY OF SPLITTINGS.

There is no specification for use when purchasing mica splittings. They are purchased against sample and experience is necessary to enable one to choose the right kind.

The reason for using thin splittings is to enable the mica to be bent around comparatively sharp corners without cracking or fracturing. For this purpose softness and flexibility are desirable features. Those accustomed to choosing splittings will be able to tell at a glance whether they are soft or hard. The former have a rather silky appearance, whereas the latter look glassy. However, appearance alone is not the only test. A quantity should be placed on the fingers, with the palm of the hand facing upward, and flexed by pressing on them with the thumb. This will enable one readily to differentiate the softness of different samples.

THINNESS OF SPLITTINGS.

The thinness of the splittings is of great importance. The thickness should be 0.8 or 0.9 mils and it will be found that in good quality lots a very large proportion are of these thicknesses, some being slightly thinner and others slightly thicker. It is surprising how a person with a little practice is able to pick out splittings of different thicknesses merely by feeling them between the thumb and fingers. In this manner it is possible to assess very quickly the uniformity of a parcel of splittings, and to accept or reject them without the laborious measuring operation entailed by using a micrometer.

SIZE OF SPLITTINGS.

Uniformity of area is another feature to which attention must be paid. The size of splittings is indicated by a number. The sizes in general use are numbers 5 and 6, these often being subdivided into groups according to size.

Number 5 splittings should have a useful area of 3 to 5⅞ sq. ins., and No. 6 a useful area of 1 to 2¾ sq. ins. If a large proportion of a case of No. 5 size contains splittings near the upper limit in area they may be offered as No. 5 superfine. No. 6 splittings may be described as superfine if a large proportion have an area of more than about 2 sq. ins. Splittings of less than one square inch area are often sold as No. 6A since there is no recognised number for splittings having a smaller area than that defined for No. 6.

It is possible, of course, to have many shapes of splittings with the same approximate area and the diagram in Fig. 38 indicates how templates may be drawn for checking whether they are of reasonable area. Whilst the outline of splittings may be very irregular it is an advantage for them to be of roughly the same general shape.

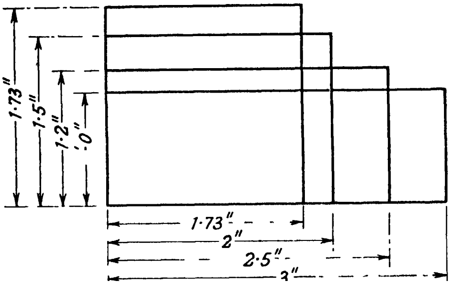


Fig. 38—Template for minimum size of No. 5 mica splittings.

Pan-packed, Dusted, and Book-form Splittings.

As the natives separate the splittings with a knife from the blocks of mica they drop them into shallow square or round tins having loose bottoms. In some cases the flakes are pressed down tightly as layers are added so that a compact mass results. These are known as pan-packed splittings. In other cases each layer in dusted with mica dust so that they readily separate when being used. They are known as dusted splittings. Some operators prefer one type of packing and some the other. It is largely a matter of individuality. As a general rule each pan of splittings is wrapped in paper before being put into its packing case. A third form is known as book-pack or book-form splittings. These are much more regular in shape and are put up in the form of packs containing 25 to 30 splittings.

Slight discolorations are often noticeable in the flakes. Provided they are not very distinct they may be ignored. Even the impurities which impart heavily discoloured regions may be harmless, but nevertheless it is not advisable to use heavily stained splittings for machine insulation.

It is not usual to apply an electric strength test to splittings. It will, however, be useful to know that the dielectric strength of good quality samples is in the neighbourhood of 4000 volts/mil for Indian mica. Amber mica is not quite so good.

Laying Splittings by Hand.

This operation is often spoken of as 'building,' e.g., one frequently hears the term building micanite. To those unfamiliar with this work the various ways of using splittings should be of interest. No. 5 splittings, being fairly large in area, are invariably laid singly, but No. 6 sizes are frequently built in patches two or three splittings thick and containing several flakes per layer, depending upon how the batch breaks away from the pack. Smaller splittings, such as No. 6A, are simply scattered over the building area in handfuls or used for building by mechanical means.

The advantage of mica is that it does not deteriorate in any way at temperatures which would completely destroy the bonding varnish and silk or paper used as a backing. It is therefore imperative that the splittings should be built in such a manner that should the supporting media deteriorate to a serious extent there is a complete barrier of mica to prevent electrical breakdown. How this is accomplished is illustrated by Fig. 39, which was made by drawing a pencil round the edges of some No. 5 splittings. They were put down in the order of the numbers. To ensure a complete barrier the splittings must overlap each other everywhere, the result being that at some places it is possible to have three thicknesses of splittings as shown at points marked A. If the splittings are carelessly built there may be places where mica is not present; these are known as bare spots and one is shown at BS. We shall discuss the implications of these triple overlaps and bare spots when dealing with mica

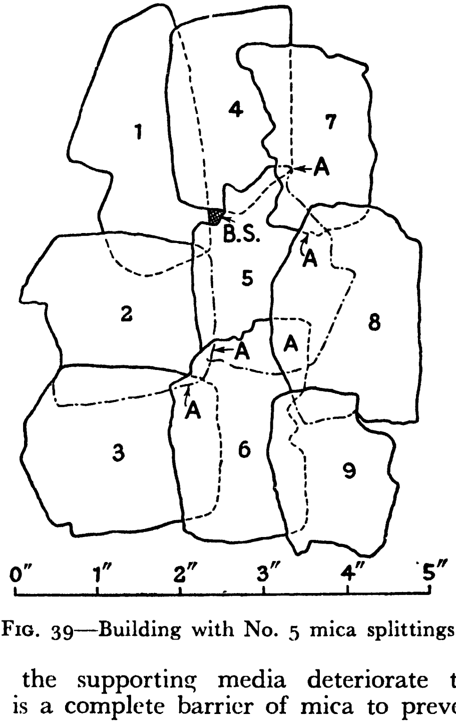


FIG. 39—Building with No. 5 mica splittings.

tape and similar products. It is important that splittings having cracks extending inwards from the edge are not used, unless the cracks are well covered by overlaps.

Work of this nature is essentially suitable for the deft fingers of girls and women, and skilled female workers can lay splittings satisfactorily at a very rapid rate. Book-form splittings can be laid more rapidly. The operator holds the thickness of splittings between the thumb and fingers and draws the hand across the wet varnished paper or silk in the manner employed when opening out a pack of cards on a table. Fig. 40 illustrates the appearance of a sheet built with book-form splittings applied by drawing the hand in the direction from the top to the bottom of the page. All these splittings were taken from one paper package, each column being built from a separate book. The sketch clearly

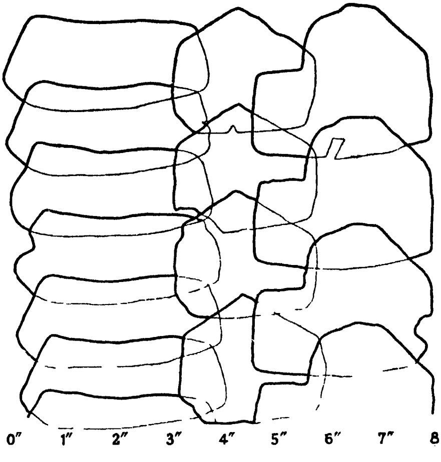


Fig. 40—Building with No. 5 book-form mica splittings.

shows that although all the splittings in a book are very much alike the shape of each book may differ greatly.

In large electrical works specialising in the manufacture of mica products, many tons of splittings are laid by hand each year. Since a ton of No. 5 splittings contains something like nine million flakes the amount of labour employed on this work is considerable.

Bonding of Splittings—Thin Micanite.

Micanite is composed of splittings bonded together without the use of backing material such as rayon, paper, etc., and how this is made merits description.

The laying of splittings on material which is coated with wet varnish seems a natural sort of thing to do and does not call for comment. However, there are many instances in which thin micanite, perhaps only one or two splittings thick, is needed. The splittings are laid in an overlapped layer, like Fig. 39, on a sheet of dry brown paper usually about 36 ins. square. When the whole area has been covered, varnish is sprinkled over the surface by shaking a brush flooded with varnish over it. Next the brush, held vertically, is dabbed all over the surface. This forces some of the varnish into the overlaps and holds the splittings in position while the varnish is carefully brushed all over the surface. A peculiar property of mica is that it does not adhere to the brush and thus become displaced during these operations. The varnish may be shellac or a flexible mica sticking varnish, depending upon requirements.

Shellac varnish is generally used for micanite of this type. If a small quantity of bond is needed it is used at a specific gravity of 0.880; for a high percentage of bond the gravity of the varnish may be 0.920.

When sheets of micanite are finished they are transferred, on the brown paper, to hot plates at a temperature of about 120°C. where they remain for a few minutes until the solvent has been driven off. They are then put on cold plates to solidify the bond. If the sheets have to be cut into pieces they are left on the paper, but are stripped off while hot if required to be used whole.

MICA TAPE WITH SILK, PAPER, OR CLOTH BACKING.

This has many forms. For the taping of individual conductors such as are used for armature coils, it is composed of a single layer of splittings with the edges just overlapped. It may have rayon or silk on one side and flexrope paper on the other, or it may have paper on both sides.

The average thickness is 4—4½ mils and the breakdown strength as made, i.e., in the moist condition, is about 2000 volts.

When required for higher voltages, such as occur in A.C. machines, the splittings are half overlapped, the thickness then being 5—6 mils and the electric strength about 3000 volts.

When discussing Fig. 39 reference was made to there being more than one thickness of splittings at overlaps. It is found in practice that these variations even out and that if the upper figure for the thickness is used for calculation the coils will fit into their slots. The lower figure may be assumed if it is proposed to press the coils before assembling in the core.

METHOD OF MANUFACTURE.

Mica tape is always made in sheet form and slit afterward. It is often made on glass topped benches which can be illuminated from below for purposes of inspection. The flexrope paper is laid on the table and brushed with the sticking varnish, care being taken to smooth out the wrinkles.

A layer of splittings is then built on the paper. The covering material, either rayon or paper, is then put in position without any varnish being put on the splittings. This makes it easier to smooth out the covering material which is done by applying varnish on top, working from the centre line towards each edge. Since rayon and flexrope paper are very porous the varnish soaks through easily and gives the necessary bonding. The material is generally made in 25 yard lengths × 18 inches wide. The building table may be only 3 yards long and when this length has been made it is lifted up and moved along so that a fresh section can be done. The part removed from the table is festooned over wooden rods or steel tubes. Completed lengths are similarly festooned and left until the varnish has dried enough to allow the tape which is slit from it being rolled up without sticking.

AVOIDANCE OF BARE SPOTS.

We drew attention to a bare spot BS. in Fig. 39. Since such a spot would have a very low electric strength and might necessitate a very expensive repair when a machine is put into service, it is imperative that these be eliminated during manufacture by careful supervision. Such a fault cannot be seen after the covering paper or rayon is in position, neither can one depend upon finding it by an electrical test of the finished sheets.

When the demand for tape is large and continuous it is built on machines. The bottom fabric or paper passes over a roller which coats it with varnish and it is then carried on a slowly moving belt. A number of girls working on each side of the belt place the splittings in position after which the top paper is laid on by passing both together between rolls. The completed material then passes through a drying oven and is finally rolled up.

MICA—CLOTH TAPE.

Cloth mica tape is made in a similar manner, the splittings—generally two layers—being built on .003 in. cloth. Sometimes the covering paper is omitted. This material averages 8–10 mils and is used for the over-taping of field coils and sometimes for slot insulation.

MICAFOLIUM.

This is the name given to mica stuck to sulphite kraft paper of the type described in chapter VI. Shellac varnish is frequently employed, but a bitumastic bond may be used when the material is required for the insulation of stator coils for 6 kV and above.

It is customary to manufacture this in long lengths, the paper being varnished and the splittings added whilst the paper is drawn along at a suitable speed. A schematic diagram of a machine for this purpose is shown in Fig. 41. The paper is carried on a spindle beneath the drying chamber. A brake is fixed to the spindle for tensioning the paper. All the rolls except the pulling rolls and the winding-up roll at the far end of the machine are idlers used for guiding the paper. The one in the trough is used for coating the paper with varnish.

Three girls sit at the end of the machine and apply splittings to the wet paper as it moves over a sheet of glass which is marked building area. A girl working on each side covers any bare spots and brushes varnish on top of the splittings. Arrangements are made on some machines for applying the varnish mechanically.

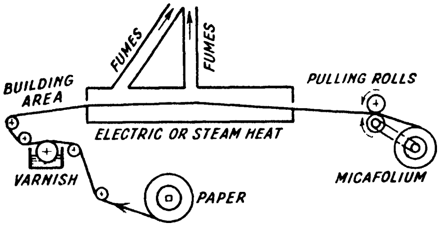


FIG. 41—Arrangement of micafolium machine.

The micafolium is pulled through a drying chamber by the pulling rolls and there is a friction drive to the winding-up roll to allow for a slower speed as the diameter increases.

MICA—PRESSPAPER SLOT INSULATION.

A useful insulation for coils and in slots is composed of mica splittings bonded with a spirit flexible varnish, having thin varnished presspaper on one side and flexrope on the other. The thickness of this sandwich material varies according to circumstances and will be referred to in later chapters which deal with the application and insulation.

FLEXIBLE MICANITE.

Flexible micanite, often strengthened with kraft or other suitable paper, is frequently used between the layers in the end windings of armatures and for reinforcing insulated conductors at cleats. Because spirit flexible varnish is less liable to " throw " when a machine is running this is the most favoured bonding medium. Since great accuracy of thickness is seldom of importance, No. 6 superfine splittings are used.

When a rigid mica insulation is needed, shellac bonded micanite is without a rival. It is made in two principal categories, moulding micanite and commutator separator micanite. There are several variations of the former.

MOULDING MICANITE.

This is used for commutator vee rings, and the cheeks and centres for field spools; for ironing on to the coil supports of armatures; lining terminal boxes, etc. Except for vee rings, variations in thickness or bond content are not generally of great importance. Consequently, No. 6 superfine splittings, and in some cases No. 6A, are employed. The thickness is varied according to needs and the percentage of shellac varies from 12 to 20 per cent.

After being built and the solvent removed the sheets are consolidated between the steam heated plattens of a hydraulic press. The temperature of the plattens is in the neighbourhood of 150°–170°C. and a pressure of 500 tons or more is applied. The softening point of shellac is raised by heating, especially if prolonged, and it is important to keep the softening point of moulding micanite as low as possible until the moulding operation has been completed. For this reason the micanite is put on hot plattens, the press is closed and full pressure applied as soon as the bond is soft enough to flow. The steam is shut off as quickly as circumstances permit and cold water is then passed through the plattens to cool and solidify the shellac quickly. The full hydraulic pressure is maintained until the micanite is cold.

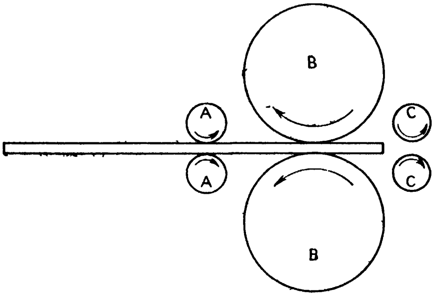


Fig. 42—Diagram of sanding machine for micanite sheets.

Commutator Vee-Ring Micanite.

For many purposes micanite of the type just described is suitable for use without further treatment. However, for commutator vee rings in particular, accuracy of thickness and uniformity are essential.

In sheets built with No. 6 splittings the number of splittings varies at different points and where they are greatest they take most of the hydraulic pressure. The thinner parts receive less and shellac tends to flow from the highly pressed parts. To overcome this, each micanite sheet is pressed with sail cloth top and bottom. This helps to even out the pressure and is known as cushion pressing.

Cushion pressing produces sheets in which the bond is fairly uniformly distributed, but their thickness is neither accurate nor uniform enough. To correct these errors the sheets are passed through a special machine, shown diagramatically in Fig.

42. The large cylinders B.B. are covered with a coarse abrasive and are driven at high speed. The sheet of micanite is forced between the abrasive rolls by the feed rolls A.A. The rear rolls C.C. serve to pull the sheet through after it has left A.A. The distance between B.B. is adjustable and it is possible to machine a sheet to within ± .001 in. of the desired thickness. This operation is known as sanding or milling micanite.

Mechanical Manufacture of Micanite.

When micanite is used in large quantities it may be built mechanically in what is known as a mica tower or snow machine.

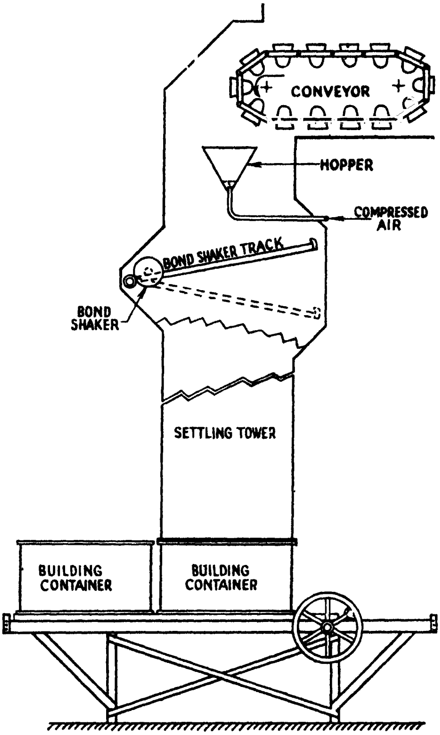


Fig. 43—Mica tower.

The operation of this can be understood by reference to Fig. 43. Small splittings of the No. 6 type are employed.

The tower is a steel structure about 30 ft. high and 3 ft. square inside. A conveyor composed of small buckets operates at the top. A weighed quantity of splittings—about 4 oz.—is put into each. When a bucket has emptied its contents into the hopper beneath a sudden blast of air blows the splittings out and they flutter down the tower and settle in the container at the bottom.

The bond is composed of shellac, copal resin, and other ingredients, together with a plasticiser, which are fused together and ground to a fine powder. This is carried in a cylinder known as a bond shaker. The bond shaker runs on an inclined track and scatters the bond by means of gauze covered perforations in the perimeter. When a predetermined number of buckets of splittings have "snowed down," the bond shaker rack, which is pivoted at one end, is operated so that the shaker runs across to the other side, scattering bond during transit.

By having a number of shakers with gauze coverings of different mesh it is possible to vary the amount of bond scattered at each traverse.

In the container at the bottom of the tower is placed a sheet of iron with a piece of brown paper on top. When the requisite weight of splittings has been deposited the mechanism is stopped. By turning the handwheel the container is moved to the left and another one brought in its place so that the operation can continue. While the second container is receiving its charge a sheet of paper is placed on the top of the splittings in the first container. Two sheets of iron are added followed by another sheet of paper in readiness for the next charge. Thus the operations continue until both containers are full.

The contents of the containers are then removed, clamped between thick steel plates and put in a stove where the bond fuses and forms the mass into sheets of micanite sandwiched between sheets of steel. After solidifying the micanite is extracted and the paper removed, after which it is cushion pressed and sanded.

Another mechanical method of building is by a plant which works by suction. A square or rectangular aperture covered with gauze is connected to a powerful exhaust fan. A box containing splittings is brought underneath the gauze and a layer of splittings is drawn up to it by the suction. The box is moved away and a container put in its place into which the layer of splittings is allowed to fall by stopping the suction. The container is then moved away and liquid bond is sprayed on the layer of splittings. The operation continues in this manner until the requisite thickness has been built. Vacuum drying is generally employed for removing the solvent, following which the operations already described are carried out.

HAND BUILDING OF MICANITE.

Mechanically built micanite is suitable for commutator separators, for micanite vee rings, which are built up in segments—commutator building is described in chapter XXIII—and for general moulding purposes. It is not suitable for commutator vee rings which are moulded in one piece. For this purpose No. 5 splittings must be used and the sheets of micanite are carefully built by hand so that they shall be as uniform in thickness as possible. They are dried on a hot plate and then lightly pressed to consolidate them: they are not sanded. The usual thickness of such sheets is 0.010 in. ± .002 in.

BOND CONTENT OF MICANITE.

For general moulding purposes the bond content, computed as described below for commutator separators, is between 10 and 20 per cent. For vee rings it should be about 10 per cent, and for commutator separators 3 to 5 per cent, never more.

COMMUTATOR SEPARATORS.

These are used for insulating the copper segments from each other and the micanite from which they are made goes through a very long heat treatment. The bond must not be more than 5 per cent or some of it may ultimately be squeezed out in service and the segments become loose. Furthermore, if bond gets under the brushes, sparking, with all its attendant evils, is liable to occur.

Great care is taken to ensure that the bond is not excessive, and to bake it so that its flow point is above the working temperature of commutators. This is done by placing cushion pressed and sanded sheets between thin sheets of steel, clamping a stack of them between heavy plates and baking at 230°C. for 12 or more hours.

SPECIFICATION AND TESTS FOR SEPARATORS.

Although mica products take many forms, only one, viz. that of micanite for commutator separators, is covered by a British Standard. This is BS. 626–1946, Micanite for Commutator Separators.

This specification states that the micanite is to be made of Muscovite mica splittings for ordinary purposes, and Phlogopite (amber) splittings when 'soft' separators are required.

THICKNESS.

The thickness at any part of a full sized sheet, when determined by a micrometer having an anvil and spindle of $\frac{3}{8}$ in. or $\frac{1}{2}$ in. diameter, is not to vary from the specified nominal thickness by more than ± $1\frac{3}{4}$ mils.

Since separators for all but the smallest machines are 0.030 in. or more thick, it would seem that the above tolerance is small enough. But this is not so. Suppose two commutators were built, each having 1000 separators, those in one commutator all being of the maximum thickness premitted above, and those in the other all of the minimum thickness. Their difference in diameter, provided all other parts were alike, would be 1.114 in. Such a difference might cause serious trouble in the correct mounting of the brushgear. To avoid this difficulty many firms which do not make their own segment micanite purchase the material cut up ready for use and stack gauged.

STACK GAUGING.

The thickness of a stack, measured as described below, should not exceed the nominal by more than ± ¾ per cent.

In stack gauging a number of segments, probably 100, are put together and subjected to a pressure of 1000 lbs./sq. ins. uniformly distributed over the whole area, at atmospheric temperature. The advantage of this method of gauging will be realised when it is stated that the possible difference in the diameter of a 1000 segment commutator is reduced from 1.114 in. in the instance already cited to 0.152 in. when using stack gauged segments.

BOND CONTENT.

The bond content, according to BS. 626, should not exceed 5 per cent computed on the original weight of the sample.

To obtain an average sample of a sheet a strip one inch wide is cut off (not too near the edge). This is then cut into pieces ½ in. to 1 in. in length, every intermediate one being taken. The weight of the sample for test should be 10 grammes. If the pieces are over weight remove a portion from each.

Place the pieces on edge in a quartz or silica crucible and heat for 1½ hours, at 500°C. in a muffle furnace. Allow to cool and weigh, then heat for a further hour at 500°C. and re-weigh after cooling. The last weight should agree with the previous weight to within 0.01 gramme. The loss in weight indicates the bond content and should be expressed as a percentage.

STABILITY UNDER HEAT AND PRESSURE.

Under the sub-heading of commutator separators we drew attention to the importance of the bond not flowing. To test for this a sample 6 in. × 3 in. cut from a full-size sheet, or a complete separator as the case may be, is subjected to a pressure of 2 tons/ sq. in. over the whole area, at a temperature of 160°C. for 10 minutes. At the conclusion of the test there should be no sign of slipping mica, exudation of bond or deformation of any kind.

SIZE OF SPLITTINGS.

It is specified that the size of mica splittings employed shall be such that not less than 75 per cent have a rectangular area of 0.5 sq. in. or over, measured on a sample 12 in. × 12 in. The sheet is disintegrated by boiling in a shallow bath containing a 15 per cent aqueous solution of caustic potash (KOH). The splittings are washed several times in hot water and dried.

They are then graded on a template of the pattern shown in Fig. 44.

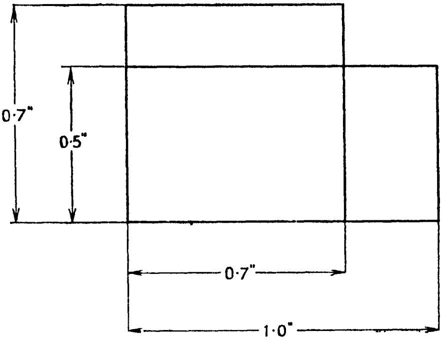


FIG. 44—Template for splittings not less than ½ square inch area.

ELECTRIC STRENGTH (PROOF TEST).

The micanite should withstand for 1 minute without failure the following stress :—

(a) Ordinary type, 250 volts/mil on the specified nominal thickness.

(b) Soft type, 400 volts/mil on the specified nominal thickness.

The material is maintained at 90°C. in air during the test and for 30 minutes before the test is applied. The electrodes must also be at 90°C.; they are of the type described in Appendix D. The voltage is raised at the rate of 1 kV per second to the appropriate test voltage.

INSPECTION OF MICA PRODUCTS.

It will have been noted that, with the exception of commutator separators, mention has not been made of electrical tests. The reason is that these tests do not serve any useful purpose since the materials are seldom used in the condition in which they leave the shop where they are made. For example, mica tape is lapped on coils or conductors; micanite is deformed by moulding; many thicknesses of micafolium are employed together, e.g. when it is wrapped round and moulded to the slot portion of a coil. In all these cases the electric strength will be different from that of the material as originally made.

Manufacturers know from long experience that correctly made mica compositions are perfectly satisfactory when applied in certain ways. It is therefore only necessary to ensure that they are properly made. We have already stressed the importance of ensuring that there are no bare spots in mica tape before the final covering is applied, and this caution applies to all other sandwiched material.

Whilst it is usual only to take an occasional check of the thickness of the sheet material used for mica tape, every sheet of micanite required for commutator vee rings or separators must be carefully gauged and inspected. For gauging a clock micrometer is carried at the end of a rigid arm so that it is supported near the centre of a flat iron plate. The finger of the micrometer is set so that it is at zero when registering the nominal thickness. It is then possible to tell, as the sheets are passed under it, whether the thickness is generally above, or below, the nominal. Visual inspection also plays an important part in ascertaining the quality of micanite. A sheet of glass is fixed with a slight inclination to the vertical so that the micanite sheets can be rested against it. A fairly powerful light is installed behind the glass.

By this means it is possible to see the following defects:

(a) Foreign matter.
(b) Uneven distribution of bond.
(c) Too great a concentration of mica in localised spots.
(d) Pulverised mica.

(a) Foreign matter generally consists of bits of wood which occasionally get into the sheets of mechanically built micanite in spite of the thorough screening the splittings receive before being used. Such imperfections are ringed round with chalk and later removed by punching out a piece of the sheet with a hand punch such as is used for cutting out washers.

(b) Uneven distribution of bond occurs most frequently in hand-built material. When the micanite is required for general purposes this fault may not be of importance, but it requires serious consideration if the micanite is for commutator separators or vee rings, or for moulding on bars to which components will be clamped.

(c) Careless building of micanite may result in too great a thickness of mica being present in localised areas. When sheets with this defect have been pressed, these spots appear as almost clear and transparent patches due to most of the bond having been forced into the surrounding space. Since for all practical purposes mica is incompressible, these areas take all the pressure and prevent the rest of the sheet being fully compressed.

(d) Pulverised mica is indicated by white opaque areas, which may disintegrate if rubbed with the finger. Since pulverisation is caused by pressure acting obliquely to the plane of cleavage, it is unlikely to be present in sheets which have been pressed between the platens of a hydraulic press. It is a fairly common complaint in commutator vee rings and further information is given in chapter XXIII, in the section dealing with the inspection of micanite rings.

It should be noted with reference to (c) and (d) above that it is possible to apply such a pressure to a piece of pure mica placed between steel plates, that it will leave an impression of its shape in them, yet the mica will not be affected in any way.

Mention has been made of the amount of bond in micanite and the percentage considered desirable for certain purposes. It is advisable to issue a warning against any attempt to assess the percentage by visual inspection, since the colour of the varnish may vary from time to time, and thereby give a misleading impression. If the colour and appearance of sheets put through in one batch vary, it is reasonable to assume that there is a variation in the bond content, but it would not be safe to make such an assumption when comparing sheets from batches made at different times. An actual test for the bond content is the only reliable method of assessment. It may be said, of course, that those who are skilled in the inspection of micanite can generally appraise the quality without the necessity of an analysis.

CHAPTER XVIII

SYNTHETIC-RESIN PAPER AND FABRIC PRODUCTS

Synthetic-resin products are commonly known as bakelite products. Thus one hears of bakelite-paper tubes and boards, etc. The fabric products comprise synthetic-resin cotton fabric or asbestos fabric. There are also asbestos paper boards bonded with synthetic resin.

Synthetic-resin paper tubes are frequently employed for the insulation of brush spindles, and in some designs metal rods with such tubes pressed on to them are used as supports to which terminals are clamped.

Paper boards are sometimes used as terminal boards and for packing blocks in windings. Cloth fabric boards may be used as slot wedges and also in packings. Asbestos fabric or paper boards are employed for the same purpose, generally where maximum class B temperatures are likely to be present during most of the operating time.

In almost every instance the resin is of the phenolic type.

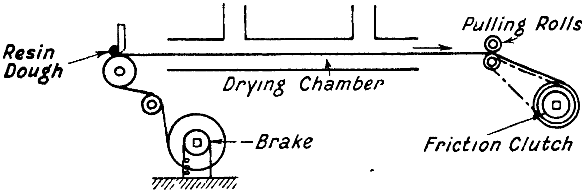


FIG. 45—Coating paper by "spreading."

COATING OF PAPER WITH SYNTHETIC RESIN.

The paper with which tubes are made is coated on one side with the resin. It may be applied in one of two ways.

One is shown in Fig. 45. In this process the resin is heated so that it becomes doughy, and the thickness of coating applied to the paper is regulated by the distance between the knife edge and the paper. This is known as the spreading method. The paper then passes through a long oven which further softens the resin, so that it tends to flow into an even thickness. The heat also partially cures the resin.

Another method is depicted in Fig. 46. The resin is dissolved in a suitable solvent, such as methylated spirit and acetone. The paper in passing over the roller, picks up the varnish, and is dried off as it goes over the large heated drum.

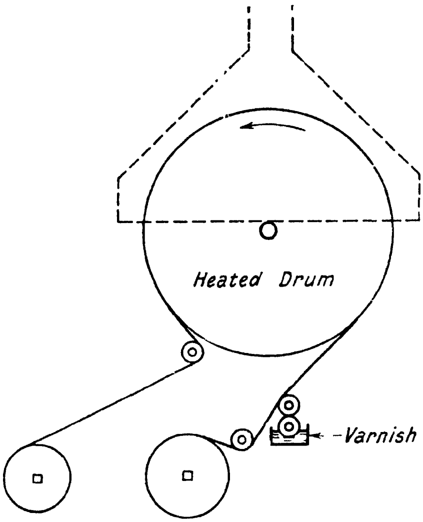


FIG. 46—Coating paper with varnish.

Figure 47 is a photograph of a coating machine showing the coated paper being rolled up. In this machine the resin is applied as a varnish.

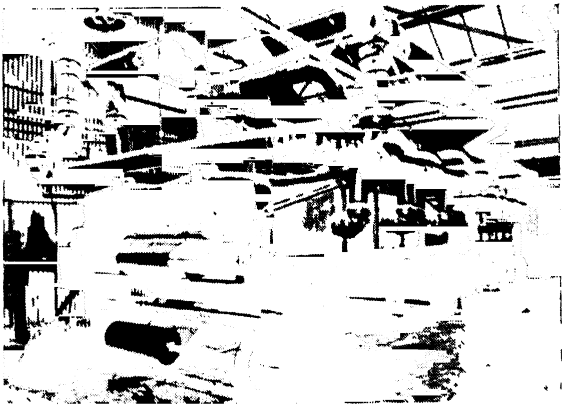


FIG. 47—Machine for coating paper with synthetic-resin. (The Bushing Co. Ltd.)

Great care has to be taken to ensure that the varnish coat is of the correct weight. This is done by taking samples periodically as the paper is being treated. The sample is weighed, the varnish is then removed by washing in acetone and after drying, the paper is also weighed The coating is generally expressed as a percentage, represented by the weight of varnish removed divided by the weight of the coated paper Thus in a 40 per cent coated paper the varnish would weigh 40 per cent of the total weight

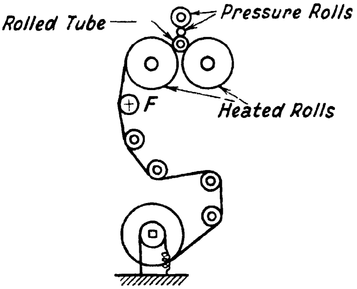


FIG 48—Rolling synthetic-resin paper tubes

Care is necessary to ensure that the resin is cured to the right degree If it is under cured, the tubes are liable to blister during the final curing process, due to the evolution of gases If over cured, the resin will not soften enough to ensure proper adhesion as the paper is wound into tubes

ROLLING TUBES

Figure 48 shows in outline the principle employed in manufacturing tubes, and Fig 49 a photograph of such a machine

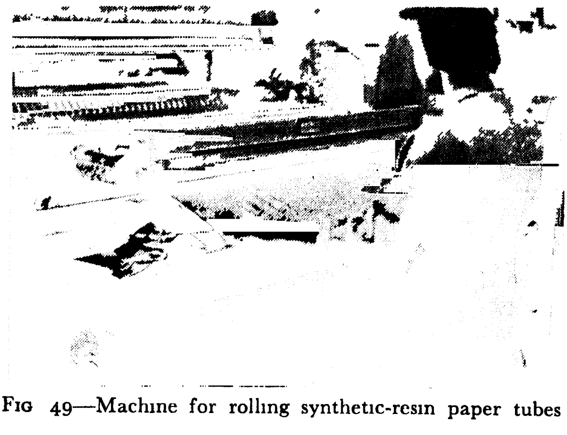


FIG 49—Machine for rolling synthetic-resin paper tubes

The coated paper is carried on a shaft to which a brake is fitted for the purpose of applying tension to the paper The small circles are idler rolls over which the paper is passed in order to even out any inequalities that may be present due to faulty batching (or rolling up) of the coated paper. F is a fixed shaft. All these together give additional tension to the paper.

The mandrel on which the tube is rolled is suitably heated before being put in the machine. It is positively driven, a short shaft with universal joints being interposed between the driving mechanism and the mandrel to allow mandrels of various diameters to be used.

The two large rolls on which the mandrel rests are free to rotate as the paper passes over them. They are heated, usually electrically, to a temperature high enough to soften the resin on the paper during the brief period it is in contact.

Heavy pressure is necessary to prevent the tension pulling the mandrel off the hot rolls. This is provided by the two rolls above it which are carried in a heavy and rigid frame. The frame is usually raised and lowered by compressed air.

Considerable experience is necessary for producing good tubes. The varnish on the paper may be rather "green," i.e., not sufficiently cured, or it may be a little over cured. These faults can be detected as the paper passes over the heated rolls, and a skilled operator will produce satisfactory tubes by varying the speed of the paper, or the temperature of the rolls, or both, to suit.

BRITISH STANDARD FOR SYNTHETIC-RESIN PAPER TUBES.

These tubes are covered by BS. 1314–1946, Synthetic-Resin Bonded-Paper Tubes for use as Electrical Insulation for Power Circuits. This supersedes BS. 316, which has been cancelled. Three types of tube are defined :—

Type A is characterised by low water absorption, high resistivity and good machining properties.

Type B has greater radial electric strength at high temperature than type A. It has higher water absorption and is, in general, less brittle than type A.

Type C has greater radial electric strength than either A or B. The water absorption is greater and its machining properties are inferior to the other two.

FINISH.

All tubes are to be uniformly and smoothly finished and free from splitting. Types B and C are to be varnished unless otherwise specified, particular attention being paid to tubes for use in air.

In the opinion of the author type C tubes are satisfactory for use in most types of industrial machines where voltages do not normally exceed 600 volts. The use of type B tubes may be an advantage for machines working in very damp situations.

The density of tubes covered here is usually between 1.05 and 1.25 grammes/cm.^{3}

Tolerance on Dimensions.

The wall thickness is ascertained by measurements on two diameters at right angles, the internal and external measurements being made at approximately the same positions. These checks are made in the 'as received' condition.

The external diameter should not differ from the nominal by more than ± 10 mils.

The tolerances on internal diameter are :—

Up to 1 inch ... ± 3 mils.
Above 1 up to 2 inches ... ± 4 mils.
Above 2 up to 3 inches ... ± 5 mils.

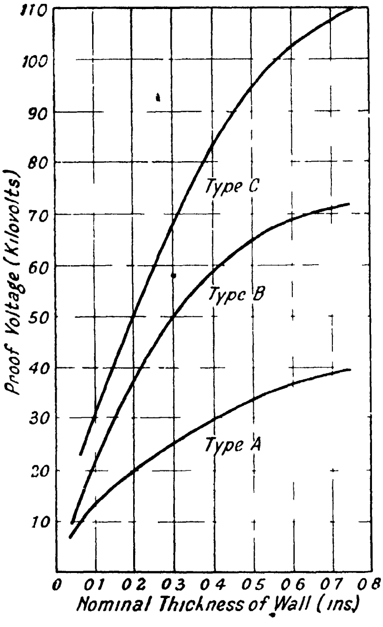


FIG. 50—Proof test voltages for synthetic-resin paper tubes.

The mean wall thickness of a tube of any size should not be less than 90 per cent of the nominal thickness.

Closer tolerance may often be obtained by agreement

Warping.

This test is made in the condition as received. The tube is placed on a flat plate and rolled. With both ends of the tube in contact with the plate it should not be possible to insert at any point between the tube and the plate, a feeler gauge thicker than (0.028 × square of length of tube in feet) inch.

ELECTRIC STRENGTH NORMAL TO LAMINAE (PROOF TEST).

The tube should withstand for one minute the appropriate voltage shown in the curve in Fig. 50. The test is applicable only to tubes with a wall thickness of $\frac{1}{4}$ in. or less.

The test is made in transformer oil, BS. 148 (any class) at 90°C. ± 2°C., after the specimen and electrodes have been maintained at the temperature in oil for not less than half an hour and not more than one hour. The internal electrode is a sheet metal cylinder sprung into position. Its length is not less than one inch plus three times the wall thickness. The external electrode is a band of sheet metal one inch long placed symmetrically with the inner one. Alternating voltage at about 50 cycles/sec. is applied.

ELECTRIC STRENGTH ALONG LAMINAE (PROOF TEST).

The sample should withstand for one minute, without failure 25 kV., 35 kV. and 30 kV. for types A, B and C respectively. This test is made in hot oil as for the previous test. It is applicable to any size of tube having a wall thickness of $\frac{1}{8}$ in. and above. The specimen is one inch long and held between parallel metal plates which serve as electrodes. The axis of the tube is to be at right angles to the plates.

SURFACE BREAKDOWN IN AIR (PROOF TEST).

The sample should withstand 15 kV. for one minute, without any sign of injury to either surface, or any appreciable temperature rise. The specimen (1 ins. long) is first conditioned for not less than 18 hrs. in a controlled atmosphere of 75 ± 2 per cent relative humidity at 20°C. ± 2°C. (Appendix B). The test is applied between parallel plates as for the previous one, in air at 20° ± 5°C.

WATER ABSORPTION.

This should not exceed 3, 8 and 20 mg/cm.^{2} for types A. B and C respectively.

The specimen is conditioned as for the previous test. It is made $1\frac{1}{2}$ ins. long by cutting the ends immediately before the test. After weighing, the sample is immersed in distilled water at 20°C. ± 2°C. for 24 hours. It is then lifted out, all surface moisture removed by wiping and re-weighed. The water absorption is given in mg. per cm.^{2} computed on the total surface area (including ends and bore) in accordance with following formula :

$$\text{Water absorption, mg/cm.}^2 = \frac{\text{mg. increase in weight}}{20\ (d + t)\ (3 + 2\ t)}$$

where d = Internal dia. in inches
t = Wall thickness in inches.

COHESION BETWEEN LAYERS (PROOF TEST).

Tubes should withstand for one minute without splitting along the laminae or showing any other sign of failure a load computed from :

Proof load = 5000 t^2 lb.

where t is the actual wall thickness in inches.

The specimen is conditioned in accordance with Appendix B and the test is carried out at between 15°C. and 25°C. The length of the specimen is made equal to its external diameter. It is subjected to a compression load in a direction perpendicular to the axis of the tube, for which purpose the specimen is placed on a flat plate, and the load applied by means of a flat plate.

MACHINING TESTS.

Every tube should be capable of being sawn, drilled and turned without showing any sign of splitting, cracking or chipping.

It is also stipulated that tubes shall not cause corrosion to metal in intimate contact with them.

SYNTHETIC-RESIN BONDED-PAPER SHEETS.

These are familiarly known as bakelite boards. They are made by pressing sheets of coated paper, often coated on both sides, between the heated platens of a hydraulic press. The resin is generally of the phenolic type and is fully cured during the pressing operation.

This material is often employed for low voltage terminal boards, and sometimes for wedges and packing blocks. A few checks of dimensions and some electrical tests may be necessary occasionally. The information for this purpose is given in BS. 1137 : 43, Synthetic-Resin Bonded-Paper Sheets for use as Electrical Insulation at Power Frequencies. It supersedes BS. 316 and BS. 547.

The specification covers sheets, boards or plates made from paper or paper pulp treated with synthetic resin and bonded together under the influence of heat and pressure.

Three types of sheet are covered by the specification :—

Type I is characterised by relatively low water absorption, high electrical resistivity in humid atmosphere and good machining properties.
It corresponds to Grade I material which was previously covered by BS. 547.

Type II has greater mechanical strength than Type I, and the water absorption is intermediate between Types I and III.

Type III is mechanically stronger and has considerably higher water absorption and inferior machining properties than Type I. It is suitable for general electrical purposes in dry situations in air or under oil.

It corresponds to Grade II material which was previously covered by BS. 316.
The density of sheets covered by this Specification may be taken as 20 cu. in./lb.

FINISH.

The sheets should be smoothly finished and free from detrimental local deformation and splitting. They should be supplied with trimmed edges.
When Type III material is intended for use in air it should be thoroughly dried after machining and coated all over with a moisture resisting insulating varnish.

FLATNESS, FOR SHEETS $\frac{1}{8}$ INCH THICK AND ABOVE.

Any sheet $\frac{1}{8}$ in. thick (nominal) and above may be tested for flatness by being placed without restraint on a flat surface, concave side up, and a light straight edge placed on it. The departure at any point of the surface of the sheet from the straight edge in any direction on the sheet shall not exceed 0.250 in. under a 36-in. straight edge, 0.110 in. under a 24-in. straight edge, or 0.028 in. under a 12-in. straight edge.

TOLERANCE ON THICKNESS.

These are given in Table 20.

Table 20.—Tolerance on Thickness of Synthetic-Resin Paper Boards.

Nominal thickness in	Tolerance mils, plus or minus	Nominal thickness in	Tolerance mils, plus or minus
$\frac{1}{64}$	2·5	Above $\frac{7}{32}$ up to and including $\frac{1}{4}$	12
Above $\frac{1}{64}$ up to and including $\frac{1}{32}$	3·5	Above $\frac{1}{4}$ up to and including $\frac{5}{16}$	14·5
Above $\frac{1}{32}$ up to and including $\frac{3}{64}$	4·5	Above $\frac{5}{16}$ up to and including $\frac{3}{8}$	17
Above $\frac{3}{64}$ up to and including $\frac{1}{16}$	5·5	Above $\frac{3}{8}$ up to and including $\frac{7}{16}$	19
Above $\frac{1}{16}$ up to and including $\frac{3}{32}$	7·0	Above $\frac{7}{16}$ up to and including $\frac{1}{2}$	21
Above $\frac{3}{32}$ up to and including $\frac{1}{8}$	8·0	Above $\frac{1}{2}$ up to and including $\frac{5}{8}$	24
Above $\frac{1}{8}$ up to and including $\frac{5}{32}$	9·0	Above $\frac{5}{8}$ up to and including $\frac{3}{4}$	27
Above $\frac{5}{32}$ up to and including $\frac{3}{16}$	10	Above $\frac{3}{4}$ up to and including $\frac{7}{8}$	30
Above $\frac{3}{16}$ up to and including $\frac{7}{32}$	11	Above $\frac{7}{8}$ up to and including 1	33

The nominal thickness is computed from ten micrometer measurements at equally spaced points around the sides of the sheet.

ELECTRIC STRENGTH NORMAL TO LAMINAE (PROOF TEST).

Specimens up to ½ in. thick should withstand for one minute the appropriate voltage shown by the curve in Fig. 51.

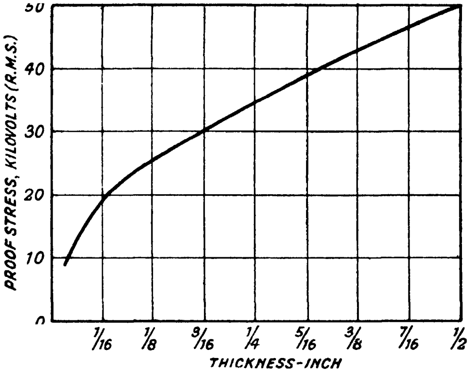


FIG. 51—Electric strength (Proof Test) of types I and III synthetic-resin paper boards.

The test is made in oil at 90°C. as for tubes, using the large electrodes described in Appendix D.

ELECTRIC STRENGTH ALONG LAMINAE (PROOF TEST).

This test is applicable to sheets not less than ¼ in. thick.

Type I should withstand 25 kV. and Type III 20 kV. (R.M.S.) for one minute.

The test is made in oil at 90°C. under conditions as already stated.

The specimen is to be 1 in. wide and the length under test not less than 4 ins. It is held between parallel metal plates which form the electrodes.

The edges of the sample making contact with the electrodes are to be finished as truly parallel planes at right angles to the surface of the material, and sharp corners are to be removed. The electrodes must be of sufficient size to cover the edges of the specimen between which the voltage is applied.

TENSILE STRENGTH.

For sheets $\frac{1}{16}$ in. thick and above :—

Type I not less than 8,000, Type III not less than 10,000 lbs./in.^{2}

WATER ABSORPTION.

The weight of water absorbed by a standard specimen after 24 hours immersion in distilled water at 20°C. (± 2°C.) should not exceed the appropriate value in the curves of Fig. 52.

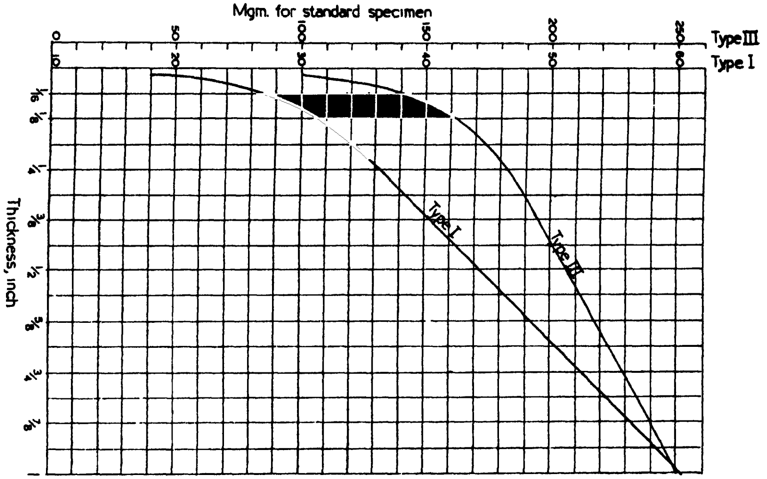


Fig. 52—Water absorption of types I and III synthetic-resin paper boards.

The specimen is made 1½ in: square, plus 20 mils or minus nil, the edges being freshly cut and smoothed with No. 0 glass-paper. Before being weighed it is conditioned in the same manner as the tubes.

After removal from the water it is wiped dry and weighed within two minutes.

Optional Tests.

The Insulation Resistance, Machining and Punching Tests which follow are optional and must be specified in inquiries and on orders if needed.

Insulation Resistance.

Of Type I sheets up to and including ½ in. and of Type III up to and including 1 inch, to be not less than 1000 megohms between each pair of electrodes. The resistance is measured at 500 volts (D.C.) after one minute's electrification, at 20°C. (± 2°C.).

Details of the arrangement are given in Fig. 53. The specimen should be cleaned with benzene (C_6H_6) after assembly and before conditioning.

Before making the test on Type I material the specimen with electrodes in position is immersed in water for 24 hours at 20°C. (± 2°C.).

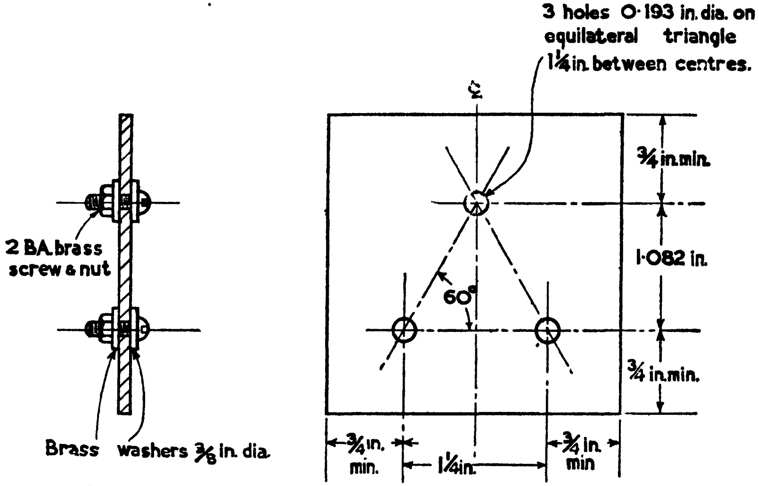


FIG. 53—Specimen and electrodes for insulation resistance test of synthetic-resin paper boards.

MACHINING AND PUNCHING TESTS.

Any sheet should be capable of being sawn, milled, drilled and shaped in a shaping machine without showing any sign of splitting, cracking or chipping.

Any sheet of nominal thickness of $\frac{1}{8}$ in. and above should also be capable of being tapped with a No. O B.A. tap without showing any sign of splitting, cracking or chipping.

When a hole $\frac{1}{4}$ in. diameter is punched in a sheet of any thickness not exceeding $\frac{1}{8}$ in. (nominal), the material should show no sign of splitting, cracking or chipping. The minimum distance between the edge of the hole and the edge of the specimen shall be equal to one and a half times the thickness of the sheet under test, but never less than $\frac{1}{32}$ in.

These tests should be carried out in accordance with the recommendations of the manufacturer of the material.

SYNTHETIC RESIN BONDED FABRIC SHEET.

Known under the familiar name of bakelite fabric this material is chiefly used for packings and wedges. In the former case it may be subject to electrical stress, and therefore certain electrical tests may be desirable.

This material is covered by BS. 972-1941, Synthetic-Resin Bonded Fabric Sheet for Electrical and Mechanical Purposes. The specification acknowledges that materials of this nature having higher insulation resistance and electric strength are available, but not included in the scope of the specification.

In view of alternatives being available it is not always advisable to purchase to BS. 972, although it should be used whenever possible.

CLASSIFICATION.

Three types are covered :—

Type A. Number of threads per inch warp and weft more than 100. Highest mechanical strength and best machining and punching properties. Normally made from $\frac{1}{64}$ in. to 4 ins. thick

Type B. Warp and weft threads greater than 45 and less than 100. Intermediate between A and C. Made from $\frac{1}{32}$ in. to 4 ins. thick.

Type C. Warp and weft not less than 35 and not more than 45. Properties not so good as B. Made from $\frac{1}{32}$ in. to 4 ins. thick.

Naturally, with such a wide range of weave, manufacturers are able to offer many grades in any one type.

Type A is useful for the brackets to which turbo-alternator stator coils are fastened. Type B is suitable for wedges and Type C for packings between coils.

FLATNESS.

As for paper boards.

TOLERANCE ON THICKNESS.

As Table 21.

Table 21.—Tolerances on Thickness of Synthetic-Resin Bonded Fabric Sheets.

Nominal Thickness of Sheet	Maximum Permissible Tolerance on Nominal Thickness, Plus or Minus		
	Type A	Type B	Type C
ins	ins.	ins.	ins.
$\frac{1}{64}$	0·0035	—	—
$\frac{1}{32}$	0·005	—	—
Above $\frac{1}{32}$ up to $\frac{1}{16}$ incl·	0·007	0·010	0·010
,, $\frac{1}{16}$,, ,, $\frac{1}{8}$,,	0·009	0·012	0·012
,, $\frac{1}{8}$,, ,, $\frac{1}{4}$,,	0·013	0·018	0·018
,, $\frac{1}{4}$,, ,, $\frac{1}{2}$,,	0·023	0·030	0·030
,, $\frac{1}{2}$,, ,, $\frac{3}{4}$,,	0·030	0·040	0·040
,, $\frac{3}{4}$,, ,, 1 ,,	0·037	0·050	0·050
,, 1 ,, ,, 1½ ,,	0·046	0·060	0·060
,, 1½ ,, ,, 2 ,,	0·057	0·080	0·080
,, 2 ,, ,, 2½ ,,	0·067	0·100	0·100
,, 2½ ,, ,, 3 ,,	0·077	0·120	0·120
,, 3 ,, ,, 3½ ,,	0·088	0·140	0·140
,, 3½ ,, ,, 4 ,,	0·100	0·160	0·160

Density.

May be taken as 20 cu. in. per lb.

Tensile Strength.

A—1400, B—10500, C—9000 lb./sq. in.

Water Absorption.

As curve in Fig. 54 for thicknesses of ½ in. and less. Actual thickness (not nominal) to be used when reading curve. For greater thicknesses of sheet reduce specimen to ½ in. thick by machining off one face; such specimens not to absorb more than 200 mg. of water.

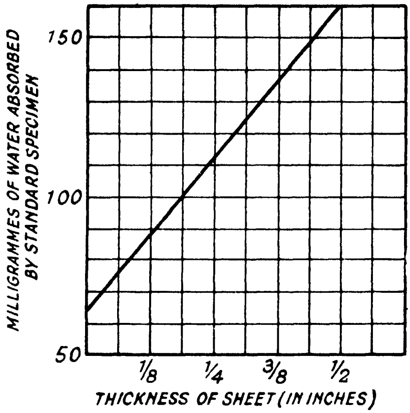


Fig. 54—Permissible water absorption for synthetic-resin fabric boards.

Electrical Tests.

The Electrical Tests are optional and must be specified in inquiries and on orders if needed. These are made on specimens prepared as Fig. 53.

(*a*) Insulation Resistance: not less than 1 megohm when test is carried out as for paper boards.

(*b*) Electric Strength (Proof) Test after immersion in Water. Shall withstand 300 volts A.C. for one minute without showing any sign of failure. Voltage is applied immediately after test (a) and between each pair of studs in turn.

(*c*) Electric Strength (Proof) Test at 90°C. Carried out in manner already described. Shall withstand 3000 volts A.C. for one minute between each pair of studs in turn.

Punching and Machining.

As for boards, except that tapping test with No. O B.A. tap is not specified.

SYNTHETIC-RESIN ASBESTOS BOARDS.

These are of two types. One is built up of woven asbestos cloth, the other of asbestos paper. These materials are employed solely as mechanical packings, etc., and their electrical qualities are not taken into account. In certain circumstances it may be advisable to apply an electric test of a suitable nature to assure oneself that the material is not a conductor.

The mechanical properties of both types are not greatly different for good quality boards, but both are much weaker than the cotton fabric boards just described, and may be very poor indeed if not well bonded.

CHAPTER XIX

COPPER WIRE AND STRIP

Copper wire and strip are such common articles that few people ever give a thought to the vast amount of labour and skill incidental to their production. For example, the ore from which the copper is obtained seldom yields as much as 1.5 per cent of refined copper, and much of it only yields about 0.8 per cent. Thus for the winding of the rotor and stator of a 50,000 kW alternator something like 1400 tons of ore have to be mined and treated.

The copper comes to this country from Canada, Northern Rhodesia and the Belgian Congo in the form of billets, or wire bars, to give them the name by which they are known in the trade. These are of refined copper, weigh about 270 lbs. and are approximately 54 ins. long with a cross-sectional size of roughly 4 in. × 4⅜ in. Before they are used drillings are taken from them and submitted to chemical analysis.

ROLLING THE COPPER.

Whilst the processes of rolling, annealing and drawing are very much alike in all mills there are differences in arrangement, and the description which follows should be considered as applying to one particular mill.

The wire bars are heated to about 900°C.—a little above cherry red heat. They are expelled from the furnace one at a time and carried by live conveyor rolls to the roughing rolls. The initial roughing reductions take place in nine stages. The first five are rectangular and the last four alternately square and oval. No manual handling is necessary during these reductions, the whole series being mechanical and operated by one man.

The oval section now passes to the finishing train which consists of seven stands, six reductions alternating from square to oval sections, the final reduction being to the finished round rod of ¼ in. dia. All these reductions are made without any re-heating. Fig. 55 is a photograph of a rolling mill in which all these reductions are made. As the sections become smaller, and the length greater, provision is made for looping them. This is done mechanically with the square sections, but manual handling of the ovals is necessary. Channels are provided under the floor of the mill to accommodate the increasing lengths of the loops.

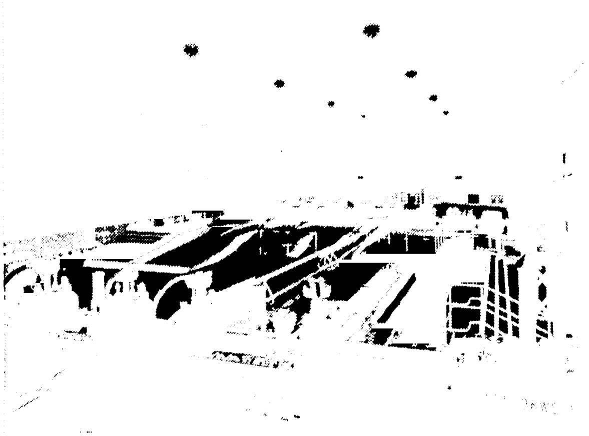


FIG. 55—Copper Rolling Mill (Pirelli General Cable Works Ltd.).

The roughing train and finishing train are driven independently by 400 h.p. motors and the finished round rod is wound in coils by electrically driven coilers which are entirely automatic in operation.

PICKLING AND CLEANING.

Coils of $\frac{1}{4}$ in. dia. rod are first prepared for drawing by pickling in a weak solution of sulphuric acid, which removes the black oxide formed in the hot rolling process. They are then thoroughly washed with water at high pressure and finally dipped in a fat solution which temporarily prevents re-oxidation.

DRAWING LARGE DIAMETER WIRES.

One is apt to think that the drawing of wire is an invention of comparatively recent date, but this is not so. It started on the Continent about the eleventh century and was in use in this country in the sixteenth century. The great advances in the technique, of course, have mostly been made during the last hundred years.

The reduction of $\frac{1}{4}$ in. rod into wire for normal use is a continuous operation. From three to nine reductions are made in producing wire between .192 in. (6 SWG) and .056 in. (17 SWG)' depending upon the finished sizes required. A machine for carrying out all these reductions simultaneously on the same length of copper requires 110 to 150 h.p. for its drive.

MEDIUM AND FINE WIRE DRAWINGS.

The drawing of finer wires involves the use of many more dies.

Thus in drawing .056 in. (17 SWG) wire down to .0124 in. (30 SWG) it passes through fifteen dies. Whilst tungsten carbide dies are used for heavy and medium wires, diamond dies are employed for finishing the finer gauges. All dies are lubricated by an emulsion supplied under pressure.

Tungsten carbide dies are made accurately to predetermined contours and used in a highly polished condition. When worn so that they yield a product that is outside the permissible tolerance, they are opened out to the next size and repolished. Diamond is the hardest known substance and the production of dies is almost an industry of its own. Diamond is the only material that will cut diamond and for this purpose it is used in the form of dust. The stones used are of the industrial type which are stained and unfit for jewellery. A stone which is to be drilled is first ground on a horizontal disc coated with diamond dust and revolving at high speed. Two faces are ground parallel to each other. The stone is then mounted in a chuck running at 6,000 to 10,000 r.p.m., and the hole is started by pressing a pointed piece of diamond, held in pliers, against the revolving stone. The stone is fixed so that the die hole will be drilled from one ground surface to the other.

After the hole has been started in this manner drilling is carried on by means of a steel needle and diamond dust, the latter being interposed between the diamond and the needle. Since wire is drawn down to a diameter of 0.001 in. it is not difficult to imagine the patience and skill necessary to drill a diamond for the purpose. Such an operation takes a week or more. Although the drawing part of the die is short the necessary taper for leading-in the wire and the opening out at the exit side make a total drilling length of at least $\frac{1}{16}$ in. When diamond dies have worn so that they yield wire which is outside the tolerance, they are opened out to the next size and repolished.

Unless the copper is free from oxide inclusions, spills, and flaws, breakage is likely to occur during the drawing operations. Alternatively the wire may tend to jam in the die and cause variations in diameter due to the extra tension causing the length between hauling sheave and the die to stretch. In fact, it would be impossible to draw the finer gauges if the copper were not free from impurities.

SQUARE AND RECTANGULAR STRIPS.

Large quantities of these are used in machines. Their manufacture is similar to the description already given, except that when drawing is resorted to it is carried out as a separate operation for each reduction. It may also be necessary to anneal the copper between some of the drawing stages.

ANNEALING.

Practically all wire and strip used for windings, whether covered or bare, is required to be as soft as possible. Copper hardens up during each reduction, whether by rolling or drawing. Hence the material is always annealed after the final draw.

Large and medium sizes are annealed by passing the coils through long muffles at a temperature of 500°C. The entrance and exit are sealed with water, the coils being carried through the seals and furnace by means of a chain conveyor. Steam is passed into the muffles in order to maintain a neutral atmosphere and prevent oxidation. They emerge in a clean and bright condition.

Fine wires are annealed in suitably heated pots. Oxidation during annealing and subsequent cooling is prevented by circulating a neutral or slightly reducing atmosphere through the pots. Clean town's gas burnt under controlled conditions provides a suitable atmosphere.

Tests for hardness and electrical resistance are made after the annealing process.

COVERING WIRE WITH TEXTILES.

This is probably the most suitable place in which to define what is meant by "mils of covering." For instance, after the size or gauge of wire a description of the covering is given thus 10/12 mils. It is very important to remember that the number of mils is the increase in the diameter of round wire or the dimensions of strip. It is *not* the radial thickness of the covering.

A textile covering may be of silk, rayon, cotton or glass. Fig. 56 is a close-up photograph of the operation of covering wire. The covered wire is seen passing vertically upward. The yarn is purchased on short cardboard tubes, the wound tube being known as a cheese. The whole lapping mechanism is carried on the horizontal disc to be seen at the bottom of the photo and rotates at high speed. A little study of the mechanism will show that the cheese has two movements. It must rotate at the same speed as the yarn is lapped on the wire and also rotate on its hollow spindle to allow the yarn to be pulled off. Hence the friction between the cheese and the spindle must be such as to ensure that it rotates with the central spindle but must not be great enough to prevent the yarn being freely unwound. This necessary friction is provided by the central spindle being split longitudinally at several points around the circumference and splayed outward. Because of occasional inequalities in the yarn snatching may occur. To adjust for this the spring controlled wire frame is provided.

A specially shaped device known as an eye is fitted at the top of the hollow spindle to flatten out the yarn and guide it on to the wire. The shape of this eye varies for different kinds of yarn. Considerable investigation was necessary before satisfactory fitments were evolved for applying glass yarn because of its abrasiveness.

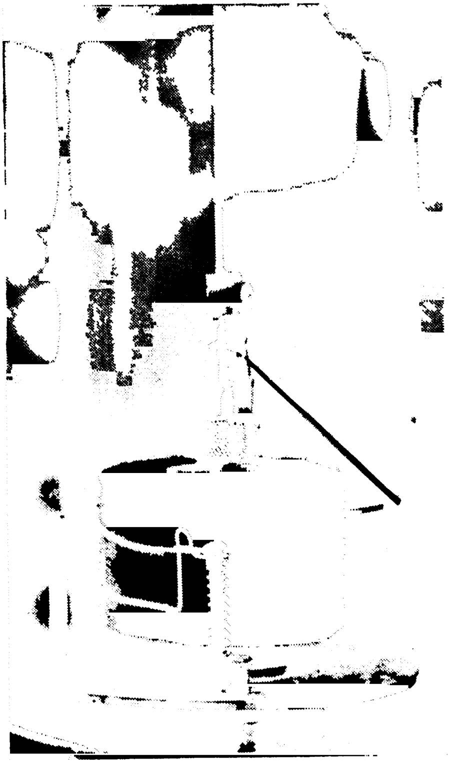


FIG. 56—Wire covering head.

Double coverings are applied simultaneously Two lapping heads, one above the other, are used as shown in Fig. 57 They are driven in opposite directions

Besides all the above variables the rate of travel of the wire relative to the speed of rotation of the lapping head has to be considered This must be varied according to the diameter of the wire otherwise the angle of the covering, or lay, will be incorrect The ply or number of ends in the yarn varies with the thickness of covering and the gauge of wire

The speed of rotation is governed by the nature of the textile. Thus whilst the head may revolve in excess of 5,000 r p m for silk, the speeds for rayon, cotton and glass are less and all different In addition to all these, special attention must be paid to the tension, which varies with the type of yarn and gauge of wire. When all these variables are considered it will be realised that the covering of wire is a very skilled and complex occupation.

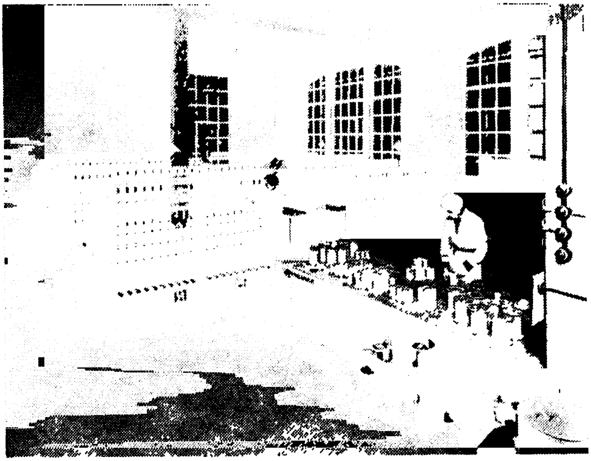


FIG. 57—Applying double coverings to wires. (Pirelli General Cable Works Ltd.).

ASBESTOS COVERED WIRES.

These come in a category of their own. Until the arrival of glass, asbestos was the only class B insulation suitable for application to round wires and the smaller sections of strip. It has been used for very many years with every success. The chief drawback is the thickness of the covering which is much greater than that necessary for glass. The electric strength of the covering should not be less than 50 volts/mil.

Two methods are employed in applying asbestos. In one case asbestos yarn is lapped on like the textile coverings. In the other it is felted on and fixed by an adhesive varnish. Between 10 and 15 per cent of cotton is incorporated in the asbestos. The result is that if a winding should accidentally be run for some time at temperatures much in excess of 120°C. the cotton may perish and leave the covering loose and friable.

ENAMELLED WIRE.

This can be classified under two headings. Ordinary enamel and synthetic enamel. Ordinary enamel is similar in composition to the linseed and tung oil impregnating varnishes we have already described. It generally contains a proportion of bitumen. Synthetic wire enamels may be sub-divided into three categories according to the nature of the covering, *viz.*, Formvar (Polyvinyl Acetal), Nylon, and a combination of ordinary enamel with an outer coating of nylon. All these, both ordinary and synthetic, are class A insulation. Wires have been coated with silicone varnish in America, but the covering is too soft and not suitable for general use at present. This covering will probably qualify as class B insulation.

Wire covered with ordinary enamel has been used in very large quantities for more than a quarter of a century and has given perfectly reliable service when the circumstances have been suited to it. The electric strength of the covering is very great; *e.g.*, if two wires of .036 in. dia. (20 SWG) having a covering of 2.4 mils are twisted together with 2½ turns per inch and voltage applied between them, it will need about 4200 volts A.C. to cause failure. If wires of the same gauge covered with double silk 3/4 mils, or double cotton covered 6/7 mils are dried out, impregnated in a normal insulating varnish and baked, and tested in the same manner, the silk pair will fail at about 800 volts and the cotton at 1480 volts.

These figures, and some which will be given later, strongly support the statement made in chapter X that a pure varnish film has a much greater electric strength than impregnated fibrous materials, no matter what their nature.

Unfortunately, ordinary enamel has very little resistance to abrasion. It is therefore unsuitable for winding armatures in which formed coils are employed. The chafing between wires during the operation of putting them into slots rubs off patches of enamel and short circuits ensue. It may be used for very small armatures in which the wire is inserted by guiding it into the slots as the armature is revolved about an axis at right angles to its longitudinal axis as shown in Fig. 81. A certain amount of success has been achieved in using this wire for winding the stators of fractional horse-power machines, but it is unsuitable for larger outputs.

The greatest use for ordinary enamelled wire is for field coils. It is no exaggeration to say that hundreds of thousands of motors are running in all parts of the world with enamelled wire field coils, often under very trying conditions, as in ships. Some of the machines are of very large output, in which enamelled wire as large as 0.080 in. dia. is used for the shunt coils. Short circuits between turns in these coils are almost unknown.

The electric strength of synthetic enamelled wire is generally lower than that of ordinary enamel, but higher than that of impregnated cotton covered wire. However, its resistance to abrasion is very great so that it may frequently be used for armature and stator windings of almost all types in which round wire is employed. It has the advantage that the covering is much thinner than that of cotton on the same gauge of wire. In consequence the space factor of the winding is improved.

APPLICATION OF THE ENAMEL.

The methods of applying the enamel differ according to circumstances. With fine wires and ordinary enamel it is usual to pass the wire through a bath of the enamel then through a pad of felt which wipes off the excess before it enters the oven. The oven consists of a number of horizontal metal tubes of about 1½ in. bore and 3 or 4 ft. long. These are fixed vertically above each other and are surrounded by a furnace. The wire passes through the top tube, through a bath of varnish and back through the second tube. It then receives another coat of varnish and passes through the third tube, and so on. The thickness of coating added each time is very small and it may require as many as six coats to provide the requisite total thickness.

For medium and large diameter wires the wire moves vertically instead of horizontally. Instead of passing through several tubes, one large diameter heated tube is used through which the wire passes several times. In this process varnish is applied to the wire as it passes from the bottom of the tube and re-enters it. It is not applied at the upper end.

These methods are also suitable for the application of nylon, but modifications are necessary when applying the formvar type. Ordinary enamel softens when it enters the heat and any slight inequalities tend to flow out. Formvar resin does not soften and flow and the coating must be applied as uniformly as possible. To ensure that this is so the wire passes vertically through metal dies which have holes of the correct size for each coating. These dies are not rigidly fixed but are allowed a slight sideways movement so that the hole remains concentric with the wire if the latter should not run true.

The enamelling process demands accurate and scientific control and there are many variables requiring control. If the wire passes too quickly through the furnace, or the furnace is too cold the enamel will be soft. Conversely, if the speed is too slow or the furnace too hot the enamel will be overbaked. In the former case the enamel will abrade easily; in the latter it may crack off when being wound round comparatively sharp corners, such as occur on rectangular field coils.

Each time the wire comes out of the heating chamber and passes through the varnish it is cooled off. It must be brought up to the correct temperature again and maintained at it long enough to bake the enamel. The larger the diameter of the wire the greater the amount of heat required. Since it is not convenient to vary the temperature of the chambers—they are controlled to within a few degrees of some fixed temperature—thicker wires have to travel through at a slower speed to ensure that they reach the baking temperature and are kept at that temperature for the required length of time. Hence a different speed of travel is necessary for each gauge of wire.

The viscosity of the varnish must be controlled within close limits. If too low the varnish coats will be too thin and perhaps overbaked in consequence. If the varnish is too thick the covering may be too heavy and uneven and the baking insufficient. Both these errors may cause pin holes in the covering.

To complicate the process further, especially with the finer wires, care has to be taken to ensure that the wire is not stretched in passing over the numerous pulleys.

ENAMELLED AND PAPER INSULATED WIRE.

This was introduced about 1933. Unfortunately it has not been the great success that everyone hoped in spite of its great dielectric strength. Two 0.036 in. wires twisted together have an electric strength in the region of 8200 volts, nearly double that of the plain enamelled wire.

Originally Japanese tissue paper was lapped on top of the enamelled wire. Flexrope paper has now taken its place. It is slit into ribbon about $\frac{1}{8}$ in. wide and applied by lapping heads similar to those used for textiles. The overlap of the paper is very small indeed and the covering is a very fine piece of work. After lapping the wire is passed through a bath of varnish and baked to make the paper adhere to the wire.

Whilst this type of wire is useful for winding small stators it has not been a success in armatures for which wound coils are used. The chafing which the wires receive often rubs off both the paper and the enamel.

Care has to be taken when winding the coils not to stretch the wire. The paper will stretch but little, if at all, and it will fracture at intervals.

ENAMELLED WIRE WITH TEXTILE COVERINGS.

Enamelled wire covered with silk, rayon or cotton is sometimes used in small machines. The covering is generally single and the idea is to take advantage of the good electric strength of the enamel and the protective and cushioning effect of the textile covering.

SPECIFICATIONS FOR WIRE AND STRIP.

There are three British Standards of interest. BS. 128-1929, Bare Annealed Copper Wire for Electrical Machinery and Apparatus; BS. 444-1932, Plain Dead-soft Copper Strip, Bars and Rods for Electrical Machines; BS. 156-1943, Enamelled Copper Wire. There is no specification for textile covered wire or strip.

As everyone connected with the use of wire or strip knows, tests of its resistance or purity are rarely made by the user. The manufacturers of the wire make careful tests, and tests by the user are seldom found necessary. For this reason only the clauses of interest to machine makers will be mentioned.

BS. 128-1929 BARE ANNEALED COPPER WIRE.

This contains tables giving various data such as the standard diameters of wires, resistances and temperature coefficients, etc. Since such information is generally available in tables issued by wire makers it will not be reproduced here. Tolerances on diameters and resistivity are not usually given in such tables so they are quoted below.

TOLERANCES ON STANDARD DIAMETER OF WIRES.

These are given in Table 22.

Table 22.—Tolerances on Standard Diameter of Wires.

Nominal Diameter of Wire	Tolerance on Diameter Plus or Minus
inch	
Up to and including 0·0032 . .	0·00009 inch
Above 0·0032 up to and including 0·01	0·0001 inch
" 0·01	1 per cent

TOLERANCES ON STANDARD QUALITY OF COPPER (RESISTIVITY).

The electrical resistance of a plain copper wire should not differ from that of a British Standard Annealed Copper Wire of the same actual diameter at the same temperature, by more than plus three-quarters of 1 per cent or minus 1.8 per cent.

BS. 444-1932 PLAIN DEAD-SOFT COPPER STRIP.

The clauses of especial interest are those dealing with finish, tolerances on dimensions, and radii at corners.

FINISH.

The strip, bars and rods should be clean and smooth, free from fins, slivers and spills, cracks and other defects. Strip should be flat and straight and, when supplied in coils, should not show twists on being unwound. When the strip is unwrapped, any edgewise deviation from a straight line should be in a smooth arc and not exceed 5 ins. in 50 feet. Strip and rectangular bars and rods should, allowing for the rounded corners, be truly rectangular.

Joints or welds shall be the subject of agreement between purchaser and manufacturer.

TOLERANCES ON DIMENSIONS.

The tolerances on the diameter of round bars and rods is ± 1 per cent of the diameter, excepting that in no case shall it exceed ± 0.004 in.

The tolerances on the width and thickness of strip and rectangular bars and rods are given in Table 23.

ROUNDING OF CORNERS.

The radii of the corners of square bars of less than 0.050 in. side, shall be agreed between purchaser and manufacturer.

For larger sizes the radii should be as given in Table 24.

Table 23.—Tolerances on Copper Strips, Bars and Rods.

Width or Thickness of Strip, Bar, or Rod		Tolerance, plus or minus	
in.	mm.	in.	mm.
Up to and including 0·010	Up to and including 0·25	0·0005	0·013
Above 0·010 up to and inc. 0·035	Above 0·25 up to and inc. 0·89	0·0010	0·025
„ 0·035 „ 0·130	„ 0·89 „ 3·30	0·0015	0·038
„ 0·130 „ 0·250	„ 3·30 „ 6·35	0·0020	0·051
„ 0·250 „ 0·500	„ 6·35 „ 12·70	0·0030	0·076
„ 0·500 „ 1·000	„ 12·70 „ 25·40	0·0040	0·102
„ 1·000 „ 2·000	„ 25·40 „ 50·80	0·0050	0·127
„ 2·000 „ 5·000	„ 50·80 „ 127·00	0·0100	0·254
„ 5·000 . . .	„ 127·00 . . .	0·0200	0·508

Table 24.—Radius at Corners of Copper Strip.

Dimensions of Strip, Bar, or Rod		Radius at Corners
Section	Thickness	
Square of 0·050 in. (1·27 mm.) side and over, and Rectangular	Up to and including 0·030 in. (0·76 mm.)	Half of the thickness (*i.e.*, the edge will be semi-circular).
	Above 0·030 in. (0·76 mm.) up to and including 0·120 in. (3·05 mm.)	One quarter of the thickness, with a minimum of 0·010 in. (0·25 mm.)
	Above 0·120 in. (3·05 mm.)	0·030 in. (0·76 mm.)

TESTING OF ORDINARY ENAMELLED WIRE.

A routine inspection and test of enamelled wire is desirable because the quality of the covering is variable. This is a factor which cannot be detected by operators or supervisors, unless the enamel is so over-baked that it readily cracks off. They are unable to tell whether the enamel is under-baked or contains pin holes.

The tests that should be applied are described in BS. 156. This specification covers two thicknesses of enamel, known as "normal" and "thick," the latter often being referred to as "double enamel" in winding shops. The tests applied to both are the same in principle, but there are differences in the appliances used, *e.g.*, wires of the same diameter are tested on mandrels of larger diameter if they have thick coverings. Naturally, different results are expected in some cases. The electric strength is specified to be double, and few pinholes are permitted in thick coverings.

It is specified that the tests should be carried out at between 10°C. and 27°C., and a relative humidity not exceeding 85 per cent.

Voltage Test.

The wire, when tested as described below, should withstand for one minute the appropriate voltage given in Table 25.

Table 25.—Voltage (Proof) Test on Enamelled Wire.

Nominal size of wire (bare), inch	Twists per inch	Test-voltage (R.M.S. values) Normal covering	
		Normal covering	Thick covering
		Volts	Volts
0·002 0 up to and including 0·003 2	4	150	300
Larger than 0·003 2 ,, ,, ,, ,, 0·005 2	3	200	400
,, ,, 0·005 2 ,, ,, ,, ,, 0·010	2½	300	600
,, ,, 0·010 ,, ,, ,, ,, 0·012 4	2½	600	1200
,, ,, 0·012 4 ,, ,, ,, ,, 0·018	2	800	1600
,, ,, 0·018 ,, ,, ,, ,, 0·028	1½	1000	2000
,, ,, 0·028 ,, ,, ,, ,, 0·048	1	1200	2400
,, ,, 0·048 ,, ,, ,, ,, 0·128	½	1200	2400

Two test samples, each 16 ins. long, are twisted together by machine so as to have the appropriate number of twists per inch shown in Table 25. A length of about 2 ins. is untwisted at each end and the enamel removed from one pair of ends for the application of voltage between the wires.

The test is made with A.C. at about 50 cycles.

Pinhole Test.

This is only applied to wires having a bare diameter of 0.002 in. up to 0.020 in. inclusive.

The number of pinholes in a 50 yard length of wire should not exceed the number given in Table 26.

Table 26.—Number of Pinholes permitted in Enamelled Wire.

Nominal diameter of wire (bare), inch	Maximum number of pinholes per 50 yards Normal covering	
	Normal covering	Thick covering
0·002 up to and including 0·003 2	20	12
Larger than 0·003 2 ,, ,, ,, ,, 0·006	15	9
,, ,, 0·006 ,, ,, ,, ,, 0·020	10	6

The apparatus for making the test is shown diagramatically in Fig. 58.

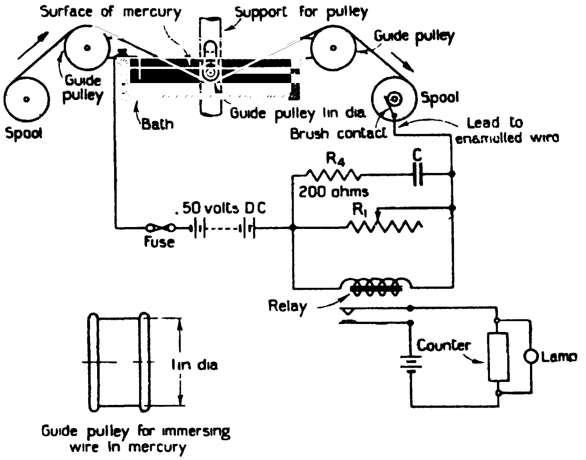


FIG. 58—Apparatus used in testing for pinholes in enamelled wire.

The guide pulley, immersed in the mercury, is of amalgamated copper and should be as light as possible when testing fine wire. The length of wire immersed in the mercury should be 2.4 ins., and it should travel at 12 ins. (± 10 per cent) per second, from which it follows that the time of immersion of each element of the wire will be approximately 0.2 seconds.

A p.d. of 50 volts D.C. is maintained between the wire and the mercury, faults being recorded by a sensitive relay. The relay should have such a sensitivity that it will be operated with certainty when 50 volts D.C. are maintained for 0.2 second across a fault resistance of 10000 ohms, but will not operate with one of 15000 ohms.

A convenient method of adjusting the sensitivity of the relay is shown in Fig. 59. A variable resistance R_1 is connected in parallel with the relay. By means of a switch, a calibrating circuit comprising a two-segment commutator, and fixed resistance R_2 and R_3, is substituted for the mercury bath and enamelled wire. The two-segment commutator is capable of being rotated at a constant speed (a gramophone turntable motor and governor are well suited for this purpose). As it rotates it connects in the test circuit the single resistance R_3 (10000 ohms) and the two resistances $R_3 + R_2$ (15000 ohms) alternately. The segments of the commutator are so arranged that the "on" period of either 10000 or 15000 ohms is equal to twice the "off" period. The speed of rotation of the commutator is adjusted so that the "on" period is 0.2 second.

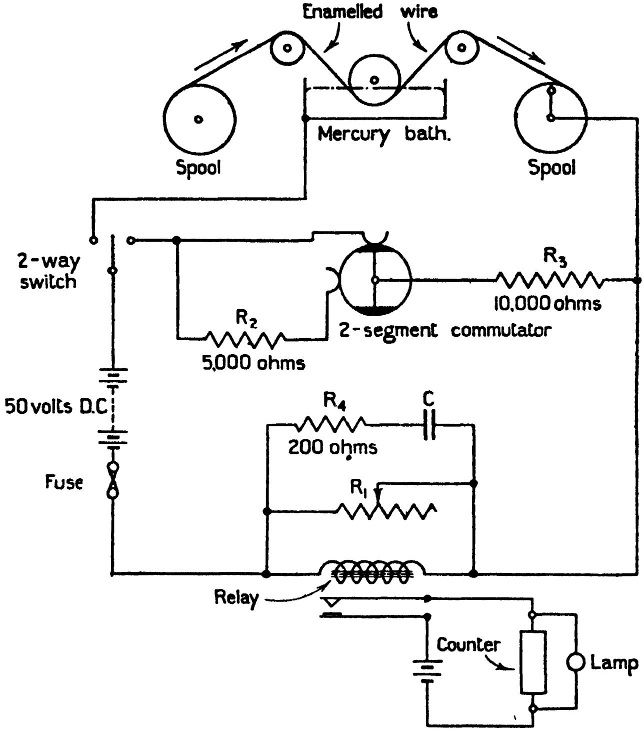


FIG. 59—Diagram of circuit for calibration of the relay for the pinhole test.

With the calibrating circuit connected, and the commutator revolving at the correct speed, the variable resistance R_1 is adjusted until the relay operates twice for every rvolution of the commutator. When this occurs the sensitivity of the relay meets the prescribed conditions.

Note.—Care must be taken not to stretch the wire in the pinhole test. It may be difficult to comply with this requirement when testing wires of small diameter, but in no case shall the resistance per yard of wire after it has been subjected to the pinhole test be increased by more than five per cent.

MECHANICAL TESTS.

There are two mechanical tests for the covering. First, after winding one layer of contiguous turns on a hard mandrel one inch in diameter, it should not be possible to remove the enamel from the wire by scraping the thumb-nail along it in the direction of winding.

The second test takes two forms according to the size of wire. For 0.002 in. to 0.010 in. inclusive, a test sample 10 ins. long is slowly and steadily elongated to 11 ins. It is then baked for one hour at 130°C. When cooled to room temperature, the enamel must show no sign of cracking or peeling when examined under a microscope with a magnification of approx. 20 diameters. For wires larger than 0.010 in. up to and including 0.128 in., the test sample is wound in contiguous turns to a width of about one inch on a mandrel, of the size given in Table 27. The wire is wound on by revolving the mandrel, care being taken not to twist or elongate the wire. The sample is then aged for one hour at 130°C. either on or after careful removal from the mandrel. When cooled to room temperature it is examined as for the smaller wires.

Table 27.—Diameter of Mandrels for Mechanical Test on Enamelled Wire of 0.010 in. Diameter (Bare) and Larger.

Diameter of Wire (Bare)	Diameter of Mandrel		Diameter of Wire (Bare)	Diameter of Mandrel	
	Normal Covering	Thick Covering		Normal Covering	Thick Covering
Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
0·0108	0·10	0·12	0·040	0·36	0·50
0·0116	0·10	0·13	0·048	0·43	0·62
0·0124	0·11	0·15	0·056	0·53	0·75
0·0136	0·12	0·15	0·064	0·64	0·87
0·0148	0·13	0·16	0·072	0·77	1·00
0·0164	0·15	0·18	0·076	0·83	1·12
0·018	0·16	0·20	0·080	0·90	1·25
0·020	0·18	0·22	0·084	0·97	1·31
0·022	0·20	0·25	0·092	1·12	1·50
0·024	0·22	0·29	0·100	1·28	1·75
0·028	0·25	0·32	0·104	1·36	2·00
0·032	0·29	0·36	0·116	1·62	2·50
0·036	0·32	0·43	0·128	1·90	3·00

Chemical Tests.

Chemical tests also are applied. For these, the samples must be free from pinholes. The enamel shall not dissolve when the sample is immersed for one hour in :—

(1) Absolute alcohol and (2) Sulphuric acid (sp. gr. 1.25 at 15.6°C.).

The temperature of the solutions is to be between 10°C. and 27°C., a different sample being immersed in each. Samples which have been immersed in the sulphuric acid solution are then washed in distilled water before being dried. They are dried for half an hour at 100°C.-105°C. The samples, when stretched or wound on a mandrel of the diameter given in Table 27 shall show no sign of peeling or cracking when examined under the microscope.

INFLAMMABILITY TEST.

A further test of the quality of the enamel is made by holding the wire horizontally in the hottest part of the flame of a $\frac{3}{8}$ in. Bunsen burner, with the flame adjusted to a height of three inches. The flame should not pass along the wire (from the edge of the applied flame) for a distance exceeding 50 times the diameter of the wire, or for a distance of $\frac{1}{2}$ in., whichever be the greater.

The specification contains a table giving the standard resistances of the wires, their maximum and minimum values, also the maximum diameter of the enamelled wire. It also states that the number of individual lengths of wire on a bobbin are not to exceed three for any size of wire, and the lengths are not to be fastened together.

TESTING OF SYNTHETIC ENAMELLED WIRE.

There is no specification for the testing of this type of wire and we are only able to indicate the routine considered necessary. The electric strength, pinhole and mechanical tests specified in BS. 156 may be applied. Although some of the synthetic coverings have a much lower electric strength than the same thickness of ordinary enamel, they will still pass the proof test figures given in BS. 156.

It is in their resistance to abrasion and the action of varnish solvents that these wires are superior, and it is in testing for these qualities that new ideas have had to be introduced.

ABRASION TESTS.

The testing for abrasion and the fixing of a standard for comparison is not an easy problem, and is still awaiting solution. Much work has been done, and still requires to be done, on this subject.

One method* is to fix a steel sewing needle in a suitable head and draw it back and forth along the wire the axis of the needle being at right angles to that of the wire. An electric circuit between the needle and the wire is closed when the enamel has been scraped away. The number of scrapes is some measure of the resistance to abrasion.

Another method† is to drag the enamelled wire across a carbonised tungsten wire fixed in a steel base. The movement of the copper wire is at right angles to the long axis of the scraper wire. A plunger which can be loaded with weights, presses the wire on to the scraper. The wire is pulled between the plunger and scraper at 2 inches per second, and the loading on the plunger is increased until an electric circuit is completed.

A third method‡ is illustrated in Fig. 60. The wire is held taut in the arm and rests on a $\frac{3}{4}$ in. diameter mild steel mandrel which is driven at 1000 rpm. Since any variation in the roughness of the mandrel would vitiate the result, it is polished with No. 0 grade emery cloth before each test. The only weight applied to the wire is that of the arm. An electric circuit is closed when the covering is worn through and the driving motor is stopped. By having a mandrel several inches long and a number of arms, several tests can be made simultaneously, as each sample breaks down it is disconnected and the motor again started. The number of revolutions before failure is some function of the resistance to abrasion.

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* "G. E. Review," May, 1942, p. 285.

† "Westinghouse Engineer," Nov., 1942, p. 124.

‡ Devised in G. E. C. Laboratory, Witton.

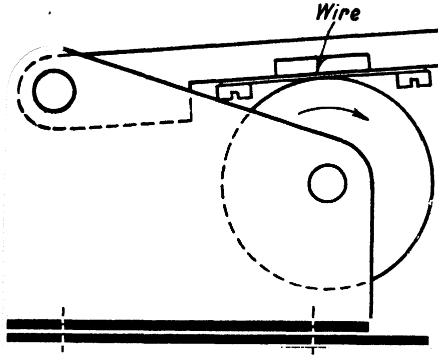


FIG. 60—Abrasion tester for enamelled wire coverings.

In order to compare samples fairly it is necessary to have some formula which will reduce all the readings to a common factor or "abrasion factor." It is not easy to do this. In the case of the scrape tester first mentioned, it is claimed that the number of scrapes is proportional to $t^{2.2}$, to $d^{1.5}$ and to $1/w^3$, where t is the thickness of film in mils, d the dia. of the wire in mils, and w the load on the scraper. Whether similar ratios hold good for the revolving mandrel is not yet certain. Even if they do, the final figures from the two methods will not be alike; one will give the number of scrapes and the other the number of revolutions. However, each method may possibly succeed in placing samples in some order of merit, provided the correct indices can be found.

ACTION OF SOLVENTS.

It is considered that synthetic enamelled wire will withstand the action of varnish solvents much better than ordinary enamel. For this test the routine specified under the sub-heading "Chemical Tests" is followed, additional samples being immersed in other solvents such as coal tar naphtha, white spirit, benzine, benzol and xylol.

A further test is to boil the wires for 5 minutes in these solvents and immediately upon removal to apply the thumb-nail test.

Ageing Tests.

Useful information may be obtained by winding the wire in contiguous turns on a mandrel tapering from $\frac{3}{8}$ in. to $\frac{1}{16}$ in. diameter removing it and examining it under a microscope for cracks. By heating the spiral for a week at 120°C. followed by weeks at increasing temperatures with periodical microscopical examinations, some idea of its ageing properties may be obtained for comparison with other types.

Cables.

From the machine manufacturers' point of view cables are perhaps the least satisfactory material he has to purchase, although they are rendered satisfactory before machines leave the factory. This is not a condemnation of cables for the uses for which they are normally made, viz., for the transmission of current for lighting and power. Normal cables are not very suitable for use in machines. Rubber covered cables quickly perish at the temperatures encountered in machines.

Cables insulated with polyvinyl chloride (PVC) were tried during the war, but were not very satisfactory at machine temperatures. This was because certain ingredients had to be omitted. Trials of post-war mixes, however, give promise of being adaptable.

Good results have been obtained with cables insulated with two layers of 5 mil varnished cambric tape, braided and compounded with a high softening point compound. These are quite good for voltages up to 550 volts. For higher voltages additional layers of varnished cotton (empire) tape are added as required on top of the braiding, cotton tape being used for the outside protective covering.

The stranding of normal cables is unsuitable for machines. They are too stiff for many of the bends they may have to take. Machine cables are, therefore, of special manufacture and contain many strands of fine wire.

Whatever covering may be used on cables, it is advisable not to put them in machines until after all drying out and varnishing has been done. These processes make the insulation very stiff and liable to crack, if for any reason the cables have to be disturbed.

Chapter XX

COMPOSITE SLOT MATERIAL; SLEEVINGS AND SYNTHETIC RESIN MOULDINGS

Before passing on to the application of insulations, it will be as well to review briefly some insulations which are not included in the previous chapters.

Composite Slot Material.

This is composed of varnished cotton or silk cloth stuck to presspaper or leatheroid with a flexible adhesive. It is often used for slot troughs, more especially for motors of fractional horse power size.

There are many combinations and thicknesses ranging from 10 mils to 30 mils but generally only 10, 12 and 15 mil material is used for the slot linings of motors. The nominal thickness may vary by ± 10 per cent.

Representative breakdown figures (instantaneous) at room temperature taken with the electrodes described in Appendix D are :—

	kV.
10 mil (5 mil presspaper, 4 mil yellow varnished cloth)	5.5
10 mil (5 mil leatheroid, 4 mil yellow varnished cloth)	7.6
12 mil (7 mil presspaper, 4 mil yellow varnished cloth)	9.2
12 mil (7 mil presspaper, 4 mil black varnished cloth)	11.2
15 mil (7 mil presspaper, 6 mil yellow varnished cloth)	10.8

The difference between the nominal thickness and the sum of the two materials is largely taken care of by the adhesive.

Cotton Sleevings (Unvarnished).

These are woven on braiding machines; a photograph of one is reproduced in Fig. 61. The cops of thread, which are arranged in two circles, are made to revolve in opposite directions around the vertical centre line of the baseplate, and simultaneously to move toward, and away from, the centre. This produces a plaiting effect somewhat reminiscent of the maypole. If, however, there is no centre, such as cable or string, on which the plaiting can rest, the operation produces a tube which is slowly pulled through the plaiting ring at the correct speed. This is arranged for by the rotation of the pulleys seen above the machine.

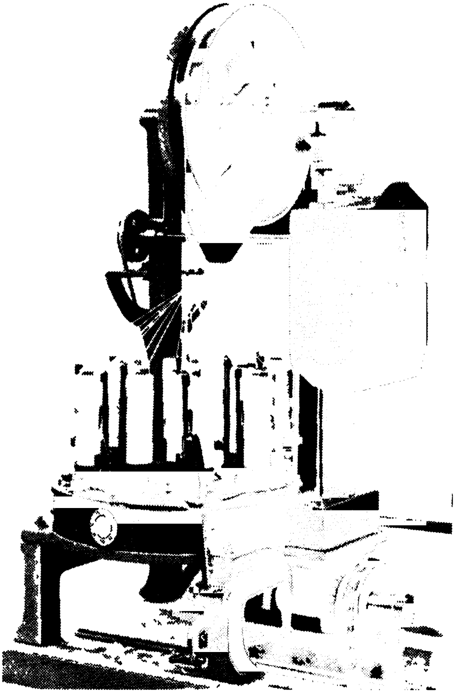


FIG. 61—Braiding Machine making cotton sleeving.
(B. & F. Carter & Co. Ltd.).

These sleevings collapse as soon as they have passed the braiding point and when short lengths are threaded on to a round rod their inside diameter can be made to vary by stretching or closing up the material. Hence, it is not convenient to designate the size by the dimension of the bore. It is better to describe their size by a rule measurement between the outside edges of the flattened sleeving. Sleeving measured in this manner may have a width of as little as $\frac{1}{16}$ in. and sizes may be obtained up to $\frac{1}{2}$ in. or more.

Short lengths are useful for slipping over the leads of armature coils to prevent the covering on the wire from coming undone. Similar sleevings are made of asbestos and also fibrous glass. Owing to the uniformity of the glass yarn it is preferred to describe such sleevings as being of a certain bore and a certain number of yards per pound weight, rather than by the rule measurement described above.

VARNISHED COTTON SLEEVINGS.

For certain purposes, such as the reinforcement of the covering on small field coil leads, or inter-connections in round wire stator windings, varnished sleevings are useful.

These are made by treating the raw sleeving so that it remains circular and then giving it two or more dips in a good insulating varnish. Owing to the necessity for baking the varnish the sleeving is generally cut into yard lengths. In this condition it is easy to measure the bore and this dimension is used to designate the size.

The bore is usually specified in millimetres, not in inches. The smallest bore is 1 mm., increasing by half millimetres up to 3 mm. and thereafter by 1 mm. steps up to 14 or 15 mms.

Discrimination is necessary when purchasing varnished cotton sleeving, as it is very variable in quality. It should be evenly braided with smooth internal and external surfaces, free from bubbles, pin-holes and creases.

The electric strength varies somewhat depending upon the weave and quality of the varnish. It is usually tested in the "as received" condition, a tinfoil band being fixed on the outside and a well-fitting metal rod pushed through the bore.

A selection of actual test figures is given below :—

Bore mm.	1	2	3	6	8	10
Wall thickness mils	14	13	15	26	27	26
Instantaneous B.D.. in kV. ...	4.8	4.9	4.5	3.6	5.3	8.3

The electric strength falls rapidly if the sleeving is bent or deformed.

An ageing test may be made by stoving the sleeving for 48 hours at 110°C., slipping it on to a soft copper rod which just fits the bore, and then bending it through 90° around rods of different diameters. It is not possible to give minimum radii for the many sizes; the test is one merely for comparing the quality of one sleeving with another.

ROLLED SILK SLEEVING.

This is sometimes known as high tension sleeving. It is made of 4 mil varnished silk formed into a tube by rolling 2 or 3 turns around mandrels of appropriate size. A suitable adhesive is used for sticking the turns together. It is usual to protect this tubing with an outer covering of unvarnished silk or rayon braided sleeving which is coated with an air drying or low temperature varnish after application.

It is made in 36 in. lengths and bores of 1 mm., 1½ mm., 2 mm., and thereafter by increments of 1 mm., the most popular sizes being up to 6 mm. bore.

This type of sleeving is much more expensive than the varnished cotton type and is only used where the electric strength of the cotton is not good enough. It is made in several wall thicknesses, the most popular being 0.5 mm., 0.7 mm. and 1 mm.

In all cases the electric strength (1 minute test) is 10 kV./mm., the instantaneous value being about 3 times this figure.

POLYVINYL CHLORIDE (PVC) SLEEVING.

Sleeving of this kind is now made which will stand normal impregnating varnishes and temperatures. The electric strength is good, being not less than 900 volts/mil for wall thicknesses of about 30 mils.

As there are so many qualities, most of them being unsuitable for use in machines, great care should be taken to ensure that they are satisfactory for specific uses.

SYNTHETIC RESIN (PLASTIC) MOULDINGS.

These are often used with embedded studs, for terminal blocks. They are usually designed so that a barrier, giving a long creeping distance, is interposed between the points to which connections are made. Phenolic resins, with suitable fillers are used in their manufacture.

The usual test is to condition them in a saturated atmosphere for 24 hours and then apply a suitable high voltage, say 50 per cent above the pressure test applicable to the machines for 1 minute.

ADHESIVE INSULATING TAPE.

This is seldom used in machines. Occasionally it may be used for binding the insulation in place when it is not likely to be electrically stressed, e.g., over the insulation on the joints of cable connections to field coils, when the two connections are well apart.

It is covered by BS. 1078–1942.

CHAPTER XXI

DESIGNING INSULATION; THE ART OF TAPING; MANAGEMENT AND THE USE OF VARNISHES, COMPOUNDS AND STOVES

DESIGNING INSULATION.

The electric strength of insulation --the most important property —is adversely affected by many factors, seven of which are discussed below. Two of them, thickness and temperature lend themselves to reasonable control, but the others are largely uncontrollable. All of them tend to lower the electric strength in some ill-defined manner. It is not surprising, therefore, that the insulating of machines does not follow any strict scientific law.

To make the assemblage still more unscientific the designer must take expediency into account. We will illustrate this briefly, by reference to a 100 h.p. D.C. motor and a vacuum cleaner, both running on 230 volts. In the former the micanite vee rings will project about an inch from the copper segments, and the slot insulation a like distance from the core. In the latter the vee rings will project about $\frac{1}{16}$ in., and the slot insulation $\frac{1}{16}$ in. It would not be expedient to use the small creepage distances in a large motor, although they seem to work well in a vacuum cleaner. The reason for this is that the motor may run many hours a day in a dirty atmosphere, whereas the cleaner will average only a few minutes a day in a comparatively clean atmosphere. Also, to apply the large creepages to a cleaner would make it unwieldly to use and grotesque in appearance. Furthermore, a breakdown of the motor might close down a large plant and put many people out of work whereas the failure of a cleaner mostly affects only one person.

It may be said with truth that the designing of insulation is an art born of long experience, not an exact science.

FACTORS AFFECTING ELECTRIC STRENGTH OF INSULATION.

A. Thickness.

A most important fact to remember is that the electric strength of insulation does not increase pro rata with the thickness. This is shown by the curves of proof voltages, e.g., Figs. 12 and 13. It is a feature which is common, in varying degrees, to all solid or built-up insulation. We may describe this phenomenon in another way by saying that the thicker the insulation the fewer volts/mil it will withstand.

B. Tension.

The curves in Fig. 62 shows how the electric strength of different varnished fabrics decreases with increasing tension. Since varnished cotton cloth tape is used extensively for machines insulated with class A materials this factor has much to do with the problem, especially as it is mostly applied by hand and the tension cannot be controlled.

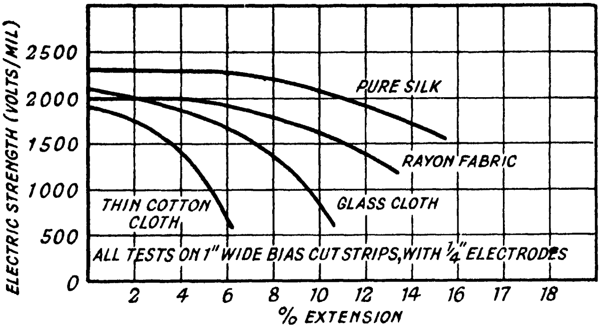


FIG. 62—Electric strength under tension of various fabrics all varnished with the same varnish to a total thickness of four mils. Instantaneous values.

C. Temperature.

In the curves shown in Fig. 63 is seen the effect of temperature in lowering the electric strength of varnished cotton tape. Other insulations display a similar characteristic.

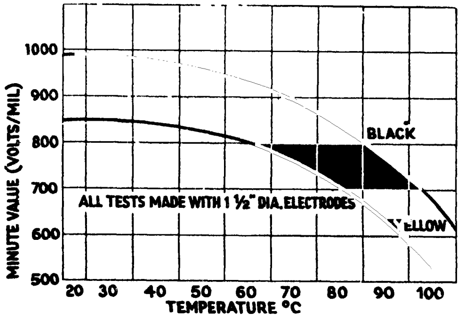


FIG. 63—Effect of temperature on the electric strength of 7 mils black and yellow varnished cotton cloths.

D. Dirt and Moisture.

Dirt and moisture play a prominent part in deciding what creepage distances should be allowed. It is not possible to reproduce in a laboratory all the varied conditions that machines may have to meet. Consequently the creepage distances allowed between various live parts and earth are the result of long experience, not of mathematical calculation.

E. Flashover Distances.

Reliable data are available for the voltage required to cause flashover or spark-over, for different distances between spheres or between needle points. But windings do not have smooth, rounded surfaces like spheres, neither are they a mass of needle points. Hence experience, rather than mathematical computation, must be the guide. It must be admitted, however, that the data available are sometimes of use.

F. Mechanical Pressure.

Mechanical pressure, such as occurs between the vee-rings of commutators, or shrunk-on slip-rings and their hubs, reduces the dielectric strength considerably.

G. Mechanical Strength.

This factor must also be taken into account. For example it is probable that a micanite field coil cheek $\frac{1}{32}$ in. thick is of ample thickness electrically, but it would not stand up to normal handling during assembly. Hence it must be made at least double this thickness.

TAPING OF COILS—IMPORTANCE OF OVERLAP.

Since the application of tape is one of the operations absorbing a large proportion of the time taken in fabricating a winding, and correct application is often of great importance, one cannot do better than give it first consideration. Copper strip which is much wider than $\frac{3}{8}$ in. cannot be satisfactorily lapped with cotton and is therefore taped. To watch a skilled operator doing the work swiftly and easily may convey an entirely wrong impression of the technique. After reading what follows, those who have never done any taping should try to tape a coil and maintain a uniform lap.

Figure 64 is reproduced from a drawing showing the taping on a conductor $\frac{1}{2}$ in. × $\frac{1}{16}$ in. with $\frac{1}{2}$ in. wide tape. Such a conductor might be used in an armature coil. The inclination of the tape

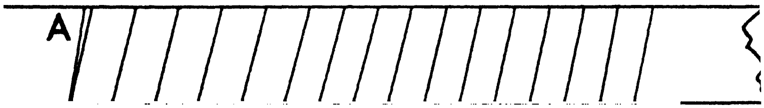


FIG. 64—Alteration in lap of taping due to the small change in inclination shown at A. The conductor is $\frac{1}{2}$in. x $\frac{1}{16}$in., and the tape $\frac{1}{2}$in. wide.

alters gradually as it moves from left to right. If it had been possible to spread this change over three or four times the length, the alteration in inclination would have been hardly noticeable. If it were actual taping it would not be possible to see the edge of the tape—represented by the lines—at a greater distance than about three feet, and very close scrutiny would be necessary to detect the alteration in the angle.

The decrease in inclination from one end to the other is shown by the angle at A in Fig. 64. It is about 3¼ degrees, and would not strike the casual observer as anything of importance. Actually it is of serious importance. The effect is to change the lap from a half-lap on the left to a five-eighths lap on the right. With a half-lap two thicknesses of tape are present. With more than a half lap, three thicknesses of tape are present in the form of a spiral along the conductor. Hence, if the tape were 5 mils thick, the effective thickness of the five-eighths lapped part would be 10 mils greater than the other part. It is general practice to assume a half-lap, or less, when designing the size of slots. There may be three segments per slot, which would mean three conductors side by side in the slot. If each were 10 mils oversize the coil would be approximately $\frac{1}{32}$ in. too wide for the slot. In order to produce approximately the same overlap on strips of different dimensions, the tape must lie at a different angle for each change in width or depth of the conductor. The difference in the angle may perhaps only be slight, but it will be realised how important it is to ensure that it is correct.

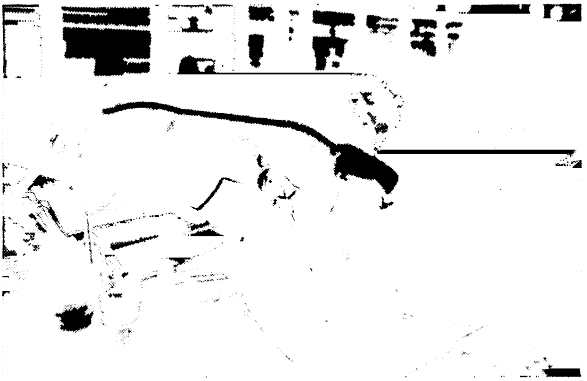


FIG. 65—Machine taping armature coils. (The General Electric Co. Ltd)

USE OF LINE ALONG CENTRE OF TAPE.

Fortunately, by an extremely simple device, it is possible to guard against the tape being lapped more than one-half. The solution is to have a coloured thread woven down the centre of the tape. Fig. 65 shows an armature coil being taped with lined tape.

Although the camera was at least nine feet from the coils the line is clearly discernible on all of them in the original photograph. If the line is not visible the lap exceeds one-half. Since the taping machine runs at something approaching 200 rpm. the usefulness of the line to the operator can readily be appreciated. The line serves another purpose. By having a different coloured thread, say red for 5 mil tape, and blue for 7 mil, it is possible to see at a glance whether the correct tape is being used.

We do not know who introduced this idea, but he should be regarded as a real benefactor to the machine manufacturer. Through avoiding the stripping of coils because the taping is too thick, it must save the industry a considerable sum of money each year. It also avoids upsetting production schedules, saves the supervisory staff endless worry, and costs little or nothing.

From an electrical point of view there is no appreciable difference between a slight overlap and a half-lap. There is consequently no point in making the operation unnecessarily tedious by insisting upon a half-lap, or nearly so. It is usual to specify taping to be $\frac{3}{8}$ or $\frac{1}{3}$ lap, and to accept anything from a slight overlap, to a half-lap, i.e., to the line being almost covered.

Large coils, such as are required for stators, are invariably taped by hand, many layers being applied according to the voltage. It may be straight-cut or bias cut varnished cotton tape, or mica tape. Bias cut tape is better than straight cut as it beds better to the varying curves. Both types are obtainable with a coloured line down the centre. This is especially useful in taping coils for say 11 kV. when there may be as many as eight layers of tape. If the half-lap is exceeded on every layer, and the author has known such cases, the coil will be almost $\frac{1}{8}$ in. over size. Mica tape, being much more fragile than varnished cotton tape, has to be applied much more slowly and the operator is able to keep to the required overlap with little difficulty.

MANAGEMENT OF VARNISHES.

Because the varnish with which a winding is impregnated is frequently of paramount importance for maintaining a good insulation resistance, it is a wise policy to employ a good quality. It is likewise very important that it should be used at the correct consistency.

Manufacturers of varnishes invariably recommend the specific gravity, or the viscosity, at which they should be used. It may be found necessary, however, to depart a little from their figures, depending upon the work in hand. Having found the most suitable consistency steps should be taken to maintain the varnish in that condition because when hot windings are dipped in it, solvent is driven off and the varnish thickens.

There are two methods of checking the consistency, by using a hydrometer or a viscometer cup. The use of a hydrometer is so well known as to need no comment, but the following formula for calculating the quantity of thinner (or reducer) to be added to varnish to reduce its specific gravity to a given figure, may be found useful.

$$x = \frac{V(v - d)}{d - t}$$

where x is the quantity of thinner, and t its specific gravity.
V is the quantity of varnish in the tank.
v is specific gravity of varnish in tank.
d is the desired specific gravity of the varnish.
If V is in gallons, x will be in gallons.

Viscometers are more sensitive than hydrometers for indicating the consistency of a varnish when the specific gravity of the thinners, or reducer, is close to that of the varnish. In such a case quite a lot of thinners could be added without appreciably affecting the specific gravity of the resulting mixture, which might in consequence have a much lower solids content than was intended. In these cases viscometers provide the most satisfactory means of regulating the solids content of varnishes.

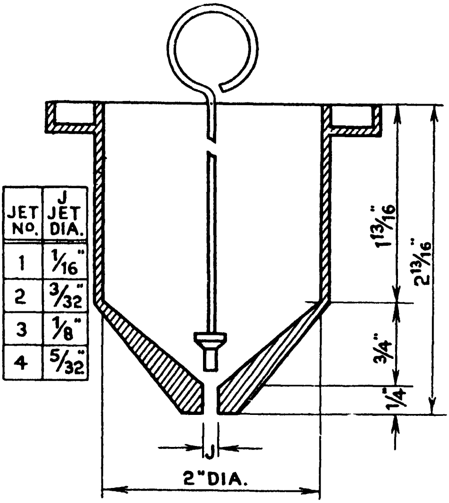


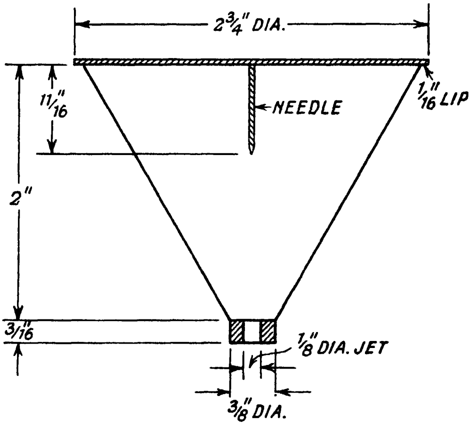
FIG. 66—Essential dimensions of Ford cup for the determination of the viscosities of varnishes.

CHECKING VISCOSITY.

The determination of viscosity in absolute (C.G.S.) units is given in BS. 188–1937. It is a difficult matter and entirely unsuited for shop use. For this purpose some standard size of container with a standard size of hole in the bottom is accurate enough. Such an apparatus was developed by The Ford Motor Co., and is known as a Ford cup. The main dimensions are given in Fig. 66. The cup is filled to the top, the plunger is then removed, and the time taken to empty is checked by a stop watch. The number 4 size of hole, or jet, is most convenient for impregnating varnishes. The viscosity is spoken of as so many seconds No. 4 Ford cup. An average varnish will have a viscosity in the region of 60 seconds, and it is not difficult to work to an accuracy of ± 2 seconds.

Another cup, known as the Lucas cup, was developed by Joseph Lucas Ltd. It is similar in principle but the dimensions are different. The viscosities given by these two can be compared fairly closely by plotting a curve between the points 50 seconds Ford No. 4 = 80 seconds Lucas, and 300 seconds Ford No. 4 = 475 seconds Lucas. Both cups are well known in the trade and it is possible to purchase varnish having a given viscosity when measured with either of them.

A third type, known as the Demler cup, originating from America, is depicted in Fig. 67. It is used by dropping it into the varnish tank and taking the time to fill up to where the image of the needle in the surface of the varnish can be seen to meet the needle point. This cup is probably more useful for measuring the viscosity of varnish in tanks than the others to which reference has been made.



WEIGHT APPROX. 32 GRAMS

FIG. 67—Demler cup for the determination of the viscosities of varnishes.

EFFECT OF TEMPERATURE ON VARNISH.

Temperature lowers the gravity and viscosity. For this reason it is advisable to do the thinning at a given temperature or else use a correction curve of the type shown in Fig. 68. The reducer should be kept in a tin near to the varnish so that it is at about the same temperature.

The use of correction curves and stop watches is generally beyond the knowledge of those who do the impregnating. It is therefore customary in works which have laboratories for a junior member to visit all tanks every day, or every other day, and supervise the adjustment of the varnish.

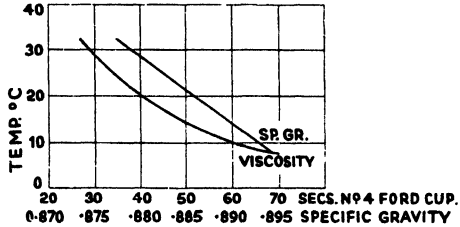


FIG. 68—Variation in specific gravity and viscosity with temperature of an impregnating varnish.

APPLICATION OF IMPREGNATING VARNISHES.

The method of application is governed by many factors, such as the size and shape of the components, the type of covering on the wire, the depth of the winding, etc.

The most important requirement is that, in order to avoid the re-absorption of moisture, all parts or windings must be free from moisture. It is also desirable that they should be impregnated as soon as they are removed from the drying oven, and while in the region of 100°C. (212° F.).

When possible, armature coils and the like should be varnished before winding into slots. This is not practicable in the case of fine wire coils. It is found in such cases, however, that if the dried-out wound parts are held so that their slots are vertical, and slowly lowered into the varnish, thorough penetration is obtained. A soaking of several minutes is given.

Windings of ordinary enamelled wire should not be impregnated. They should be given a quick dip so that the varnish will seal the outer layers of the end windings, but not enter the slots to any appreciable extent. Windings of synthetic enamelled wire may be soaked, if necessary.

Armatures and rotors of more than a few inches in diameter, and which are wound with varnished coils, are often impregnated in a manner to prevent varnish entering pockets in the winding or core. When varnish enters pockets it is not always possible to drain it out. It skins over during the subsequent baking, and when the machines are run the skin bursts and the well known phenomenon of varnish throwing occurs. The method of impregation in this case is to support the armature or rotor, with its shaft horizontal, over a bath of varnish and partly immersed in it so that the lower coils are covered by the varnish. It is then slowly rotated so that all the windings receive a thorough coating.

Medium sized stators are usually totally immersed in the varnish.

Larger stators, which cannot be treated in this manner, have their end windings varnished by spraying or pouring varnish over them. Since large machines are generally for higher voltages, their windings are already covered with moisture-resisting insulation and it is only necessary to seal the outer layer of cotton tape.

Vacuum impregation in varnish is sometimes employed for small windings, but is not often favoured for anything larger than fractional horse-power sizes, except very high voltage machines. The chief objections to this process are the great size of plant required for impregnating large numbers of parts, such as industrial motor stators, and the slowing-up of the production if the plant is not capable of accommodating peak outputs. It is known that the methods just described give quite good results for normal service.

Many firms make a practice of giving the windings two immersions in varnish. With a normal drying varnish the first coat is thoroughly baked before the second is applied. With synthetic varnishes, which require a pre-baking at about 80°C. for two hours or so, the second impregnation is applied at the end of this period. A second pre-bake is then given, followed by the requisite final bake at high temperature.

TREATMENT OF FIELD COILS WITH VARNISH.

Different treatments are used depending upon the type of wire and size of coil. Coils wound with ordinary enamelled wire should not be soaked in varnish. If they are taped all over they may be dried out and then given a quick dip in varnish so that it does not penetrate into the winding but thoroughly saturates the tape. On the other hand, coils of synthetic enamelled wire may be soaked if desired, provided the varnish has not a methylated spirit solvent or one composed of a mixture of xylol and butanol. If in doubt about the effect of the solvent it is better to give a quick dip. In cases where coils have to be bent to the curvature of the shell, as often happens in table fans and fractional horse-power machines, it is advisable not to soak them.

Enamelled wire coils wound on spools and not taped all over, need only be brushed on the outside layer with a pigmented enamel such as grey heat resisting enamel, followed, when dry, with a coat of black finishing varnish.

Small coils of silk or rayon covered wire are often impregnated in ordinary insulating varnishes. If they have to fit the curvature of a shell it is best to bake them after fitting in position.

For cotton covered wire coils, immersion in varnish after drying out may be employed. Since ordinary varnishes will not dry inside coils for a very long time, and may ooze out in service, oil modified synthetic varnishes which will harden by polymerisation should be used.

IMPREGNATION OF FIELD COILS IN COMPOUND.

Without doubt the best treatment for cotton covered wire coils, is vacuum impregnation in compound, provided their radial thickness is not too great to permit thorough penetration. Certain aspects of this problem are discussed in Chapter XVI, and it is only necessary now to describe the actual process.

A diagrammatic arrangement is shown in Fig. 69. The compound is held in a heated storage tank in which it is kept molten, and is agitated by a revolving paddle. Coils are put in the impregnating chamber. This is heated and is connected to a vacuum and pressure pump. A vacuum of not less than 28 ins. of mercury is applied for at least 2 hours, after which bitumen is allowed to flood the impregnating chamber. The valve between the two sections is then closed and an air pressure of at least 80 lbs/sq. in. is applied above the bitumen to force it into the coils. At the end of the pressure period, usually one-half to one hour, the valve is opened and the compound is forced back into the storage tank by the compressed air. The air pressure is then removed and the coils allowed to drain for a period before opening up the impregnator.

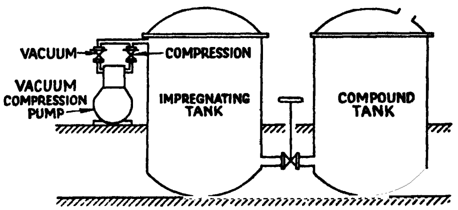


FIG. 69—Vacuum Impregnating Plant using compound.

CHECKING OF DROPPING POINT OF COMPOUND.

In impregnating plants the compound is often kept fluid for several weeks. Under these conditions, some of the lighter fractions are driven off, and the dropping point rises. If this happens, too much compound may cling to the windings of untaped coils and give trouble by slowly creeping when the coils become hot in service. In the case of taped coils, the penetration may be insufficient. To avoid these troubles it is customary to check the dropping point at regular intervals and add fluxing oil to the compound to reduce the dropping point to normal. Fluxing oil is very dark in colour and is generally obtained from the refinery where the compound is made.

TREATMENT OF VERY LARGE FIELD COILS.

If the coils are too large for thorough penetration by compound it is usual to brush them with varnish layer by layer during winding. The grey pigmented heat-resisting varnish was much in favour before the advent of the oil modified synthetic varnishes. The latter are now being used for this purpose. Coils of rectangular or square strip are generally treated in this way because bitumen does not penetrate such coils in a satisfactory manner.

When a cotton covered or taped strip series winding is wound on the top of an enamelled shunt coil, it is usual to brush this winding with varnish, since it is not advisable to impregnate enamelled wire in bitumen.

Finally, there are coils of glass insulated wire. These are invariably varnished with an appropriate synthetic varnish. If of a suitable size for penetration by immersion this process is employed. Alternatively, the coils are brushed with varnish during winding.

APPLICATION OF FINISHING VARNISHES.

It is customary to apply these varnishes immediately the parts are removed from the stove at the end of the final bake. Small and medium sized windings may be dipped in the varnish; larger ones are sprayed. In general these varnishes will dry on the hot windings without any need for further stoving.

GREENING.

Coils which have been impregnated in a light coloured varnish sometimes exhibit a green colour after baking. The general opinion about this phenomenon is that it is due to moisture in the insulation acting as a vehicle for the acids in the varnish and enabling them to attack the copper. From this reasoning has come the popular idea that if coils are green they were not fully dried out before impregnation. Whilst this may be true in some cases, it is not always the explanation. Copper strip which has been in stock for a long time and become discoloured or dirty in consequence may exhibit greening after being taped with cotton tape, thoroughly dried out, and impregnated.

Careful tests have shown that the copper salts which produce the green colour are insulators. The corrosion of which greening is indicative may cause open circuits in very fine wire coils, wire of say 0.0124 in. diameter (30 SWG) or smaller, but there is no evidence of it being responsible for failures in other cases. Whilst regular greening should be avoided, we see no reason to worry if an occasional batch of coils shows slight greening. This phenomenon is not seen when black impregnating varnishes are used. Since these are made with the same types of oils there is no reason why the action should not occur. The probability is that the black colour masks the green.

BAKING OVENS.

Baking ovens vary in size considerably. In a small shop in which fractional horse-power parts are wound they may be only the size of a domestic oven. In a large works they may be as much as 20 feet cube.

For the smaller stoves electric heating with thermostatic control is quite general. Large stoves may be heated by hot air. This has the advantage of supplying plenty of oxygen for the setting of the varnish. Another method, frequently used in large factories where process steam is available, is by circulating the steam through suitably disposed pipes. The pipes are usually arranged in groups under the floor, which may consist of iron grating, and also in banks reaching part way up the walls.

Whatever may be the system of heating, it is essential that adequate ventilation is provided. Fresh air should enter at the bottom and pass over the source of heat. Dampers are generally provided in the outlet at the top. These are sometimes closed down when an oven has just been loaded, so as to raise the temperature of the parts quickly. They should be so constructed that ventilation can never completely cease if a neglectful attendant forgets to open them fully at the appropriate time, although there may still be insufficient air for proper drying and oxidation. It is considered that the flow of air should be such that the content of a stove is changed not less than six times each hour for oxidising varnishes. A similar rate is desirable during the low temperature baking of synthetic varnishes, but very little change of air is necessary during the high-temperature bake, since the hardening of the varnish is chiefly by polymerisation and not by oxidation.

TEMPERATURE RECORDERS.

In a small shop, where the responsible person may take a personal interest in all the work, an easily read thermometer may suffice. However, in a large works, where ovens are frequently opened during the day, and probably kept closed all night, a recording thermometer is invariably installed on each oven. One with a seven-day recording chart is much better than one with a daily chart. The former enables an executive to see how the ovens are being used; a daily chart is mostly changed early in the day and may never show anything of interest at the time of the executive's itinerary.

Large stoves may vary in temperature at different points and a recorder, or thermometer, will only record the temperature in the vicinity in which its bulb is located. It should be placed in a position of average temperature, whenever possible. Experience will indicate what temperature should be recorded to ensure proper baking of all parts put into the stove.

PRE-DRYING.

Pre-drying should be done at not less than 100°C. (212° F.) to ensure that practically all free moisture is driven off. It is usually done at 105°–110°C. The time taken depends upon the articles being treated. Coils such as those for armatures, etc., which have not much heat capacity, or much material on them for retaining moisture, may be dry and ready for varnishing in a couple of hours.

The pre-drying of fractional horse-power windings requires at least four hours. Larger windings may require twelve hours or more. For long drying times it is customary to load the stoves as windings become available and leave them all night with full heat on the stoves. Whilst this may result in some windings being pre-dried much longer than others, it does ensure that those put in last receive an adequate drying time.

Baking Impregnated Windings.

As in the case of pre-drying, factory routine governs this problem to a large extent. Thus, if pre-drying has been done during the night, impregnating may be done in the morning and the baking completed during the day. In general it may be said that the aim is to ensure that windings receive not less than the minimum baking necessary, and often a longer baking. Increasing the baking time by a few hours, does not do any harm, provided the temperature is not greatly in excess of that recommended by the varnish maker.

Increasing Oven Temperatures.

The advent of synthetic varnishes has introduced the problem of increasing baking temperatures. If a higher steam pressure is available or the stoves are electrically heated, the increased temperature may be obtained without much trouble. We would emphasise that a synthetic varnish which requires to be stoved at 135°C. will not be satisfactory when stoved at say 110°C., even if the time be doubled. It may set hard and the windings may show a good insulation resistance shortly after cooling down. When in service, however, it will be found almost impossible to maintain a good insulation resistance in a damp atmosphere.

It is uneconomic to attempt to increase the temperature of steam heated ovens by adding other forms of heating such as placing a few electric heaters in the space. The steam pipes will remain at their own natural temperature and therefore extract much of the added heat.

Other Methods of Pre-drying and Baking.

When large numbers of small windings are being handled pre-drying and the baking of the varnish may be done by passing current through them. Such a method requires skilled supervision to ensure that over-heating does not take place.

Another method that is increasing in popularity is pre-drying and baking by radiant heat. The radiant heat may be provided by specially designed electric lamp bulbs or by gas heated panels.

With this system of heating it is quite common to suspend the parts from a conveyor and pass them between banks of heaters. A novel and efficient mass production method for the varnish impregnation of electrical components, has been developed and is known as the Zanderoll Process.* The heat may be supplied by electric or gas radiant heat methods, or by high velocity air convection methods.

The plant shown in Fig. 70 consists of three lots of radiant heat units, each unit comprising a number of banks of lamps arranged to form a tunnel. The three lots may be in line, or, as in the illustration arranged to form three sides of a square. Circular discs are fitted to each end of armature shafts so that as they are dragged along rails they rotate at approximately 1 rpm. Suitable fittings are attached to stators to ensure rotation.

The method briefly consists of raising the temperature of the article to be treated to 180°C., and then rolling it through a tray of varnish placed between the first and second tunnels of heaters. The component makes one or more rotations whilst passing through the varnish and continues to rotate during the baking period. A second varnish treatment and bake is customary. The trays holding the varnish are supplied from a cooled stock tank.

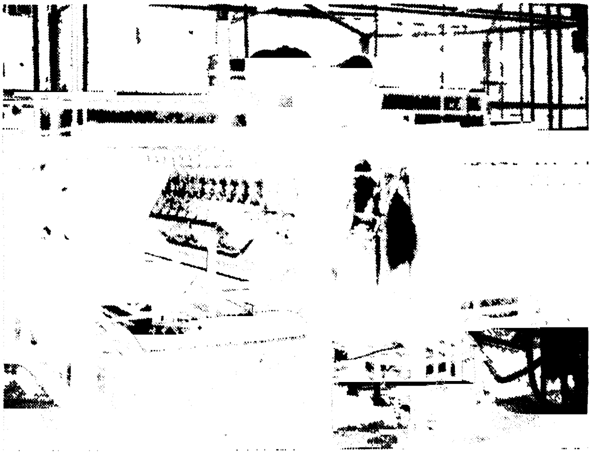


FIG. 70—Pre-drying and baking with radiant heat. (The Sterling Varnish Co. Ltd.).

The plant is designed so that the temperature of the component emerging from the varnish is above the boiling point of the solvent, and by this means the varnish penetrating into the winding is substantially solvent free. In this way the baking time is very much reduced compared with the usual baking periods for normal varnish soaked components.

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* The Sterling Varnish Co. Ltd. Patent No. 58445.

The high velocity air convection method of heating is one which is now coming to the fore, and consists of an oven into which is passed air which has been heated in a gas or oil fired combustion chamber. It is then re-circulated into the combustion chamber with or without bleeding the system to ordinary atmosphere. The temperature of the air used for heating electrical components can be as high as 200°C., and it is claimed that extremely rapid baking of varnishes may be accomplished by this method. It has the advantage of quickly removing the solvent fumes from the impregnated components; in other words, it is self-ventilating.

DRYING OUT OF LARGE STATORS.

Frequently it is not convenient to put large stators in an oven, in which case they are dried out by current being passed through them. The usual practice is to assemble a machine and run it on short circuit. The excitation and speed are kept low to avoid overheating. If it has a closed ventilating system arrangements are made for a gradual change of air during the drying-out period.

CHAPTER XXII

PROCESS TESTING DURING THE WINDING OF MACHINES

It is general practice to make periodic tests as the winding of parts progresses so that if any fault develops it is discovered and corrected with the least possible disorganization. It is these tests which are described in this chapter.

HIGH VOLTAGE TESTING.

High voltage tests are applied at suitable stages during the winding operations.

What these stages are and the value of the voltages will be recounted in subsequent chapters dealing with specific types of windings.

The values of the voltages are based upon the final high voltage test as given in the various British Standards for electrical machines. A list of these standards is given in connection with Table 1, chapter II.

Table 28 is a reproduction of the high voltage tests taken from Table 2 of BS. 168–1936 and shows the type of instruction given. This table may be taken as a summary of those appearing in most of the other British Standards for machines.

The voltage is to be alternating at any frequency between 25 and 100 cycles/sec. In general a frequency of 50 cycles/sec. is employed in this country. The voltage is increased to the test voltage as rapidly as is consistent with its value being indicated by the measuring instrument, and maintained at the full value for one minute. It is applied between the winding and the frame of the machine with the core connected to the frame and to the windings not under test; e.g., if one phase of a three-phase winding is being tested the other two phases should be connected to the frame. It is usual to connect the frame to earth for safety.

The specification stipulates that these voltages shall be applied only to a new and completed machine in normal working condition, and unless otherwise agreed, shall be carried out at the maker's works, preferably at the end of the temperature test of the machine.

A most important clause in all the specifications is to the effect that if a machine has passed its high voltage tests and for some

Table 28—High Voltage Tests for Industrial Motors and Generators.

Item No.	Machine or Part	Test Voltage (R.M.S.)
1.	*Machines of Sizes 1 b.h.p., kW or kVA and above, but below 3 b.h.p., kW or kVA per 1000 r.p.m.	1000 V + twice the rated voltage.
2.	*Machines of Sizes 3 b.h.p., kW or kVA and above per 1000 r.p.m.	1000 V + twice the rated voltage with a minimum of 2000 V.
3.	Field windings for synchronous generators when the excitation voltage does not exceed 750 V.	10 times the excitation voltage. Minimum, 2000 V. Maximum, 3500 V.
4.	Field windings of synchronous motors:—	
	(*a*) When intended to be started up with the field windings short circuited or connected across the exciter armature.	10 times the excitation voltage. Minimum, 2000 V. Maximum, 3500 V.
	(*b*) When intended to be started up with the field windings separated by a field-dividing switch.	5000 V.
	(*c*) When intended to be started up with the fields on open circuit and without a field-dividing switch.	5000 V when the excitation voltage is less than 275 V. 8000 V when the excitation voltage is equal to or exceeds 275 V.
	(*d*) When intended to be started up with A.C. windings idle.	As for Item 4 (*a*).
5.	Field windings of synchronous induction motors intended for rheostatic starting.	1000 V + twice the maximum voltage that could be induced between the terminals.
6.	Secondary (rotor) windings of induction motors not permanently short circuited.	For non-reversing motors, 1000 V + twice the maximum voltage which could be induced between the slip-rings. For reversing motors, 1000 V + four times the voltage between the slip-rings at standstill on open circuit with full primary voltage applied to stator windings.
7.	(*a*) Exciters	As for the field windings they are intended to excite.
	(*b*) *Exception*—Exciters of synchronous motors and synchronous induction motors, if connected to earth or disconnected from the rotor-field-windings during starting.	As for Item 3.
8.	Separately-excited field windings of D.C. Machines (including Exciters).	1000 V + twice the maximum voltage of the circuit for which they are excited. with a minimum of 2000 V.

* For two-phase windings having one terminal in common, the test values indicated in Table 2 shall be increased 40 per cent; the rated voltage shall be taken to be that of each separate phase.

reason it is desired to have a further high-voltage test after erection on site, the additional test voltage shall be 75 per cent of that given in the table.

INSULATION RESISTANCE.

The insulation resistance in megohms when the high voltage test is applied should not be less than :—

$$\frac{\text{Rated volts}}{1000 + \text{Rated Output in kVA. or b.h.p.}}$$

The insulation resistance shall be measured with a D.C. voltage of about 500 volts, applied for a sufficient time for the reading of the indicator to become practically steady, such voltage being taken from an independent source or generated in the measuring instrument.

Insulation resistance in megohms appreciably higher than the number obtained from the formula given above should not be specified for electrical machinery, since in order to obtain it, long baking at high temperatures may be necessary and this may permanently damage the insulating material.

In drying out windings which have been exposed to damp for a long period, fictitious values of insulation resistance are often obtained when only a portion of the insulation has become dry, the insulation as a whole being still in a dangerous condition.

In drying out such windings it is therefore necessary to ensure by long continued careful drying that the insulation resistance shall actually reach a stable value of the required magnitude before the high voltage test is applied.

TESTS FOR SHORT CIRCUIT AND OTHER FAULTS.

Short circuits may occur from a number of causes. Coils may be a very tight fit in their slots and the force employed in fitting them may result in damage to their coverings. Tensioning devices applied to wire or strip while it is being wound into coils may remove some of the covering. If strip coils are mica taped, there may be a few bare spots in the mica. These may not show up as absolute short circuits in the early stages of manufacture but may develop later, and suitable tests should be applied for discovering them.

Other faults for which tests must be made are open circuits, sometimes present in fine wire windings of various types, and reversed coils in armatures and stators.

ARMATURE AND ROTOR FAULTS.

Armature and rotor coils of more than one turn may be tested for short circuits by lowering batches of them over one of the outer limbs of the apparatus illustrated in Fig. 73, and described later. This is not such a searching test as the transformer test on a wound armature or rotor since the conductors are not held in such intimate contact as when in their slots.

In coils of one turn per segment there are generally two or more conductors side by side in the slot. Each group, forming a half coil in the slot, may be taped together or be surrounded by micanite tubes moulded on the slot portions. In such cases a test is made between adjacent conductors with 230 volts, a lamp being connected in one test lead for indicating a fault and to limit the current if there should be a short circuit. Since the voltage between conductors when in service seldom exceeds 20, this test provides an ample margin of safety for normal machines. If, however, the conductors are mica taped and required for arduous duty, such as in traction motors, the test between them may be 1000 or 1500 volts.

TRANSFORMER OR "GROWLER" TEST.

The most searching test for short-circuits is the transformer test, often known as the "growler" test because the mechanical vibration caused by the alternating flux sets up a noise similar to a growl.

The apparatus used for this test is depicted in Fig. 71. It consists of an electro-magnet built up with laminations, the coil being excited with alternating current, preferably at 100 cycles/sec. An armature under test is supported with its shaft horizontal and resting in vee blocks lined with leather. The growler is suspended by wire ropes over pulleys and counter-weighted so that it can be lowered on to the armature.

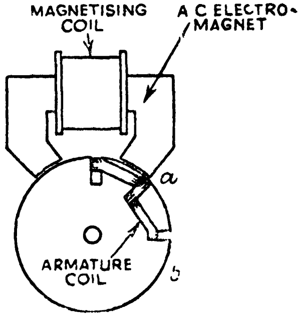


FIG 71—Transformer test of an armature for short-circuits

The alternating flux passing through that portion of the armature core embraced by the poles of the magnet will pass through all the coils in the slots which are in its path An e m f will be induced in those coils, and current will flow if a short circuit in a coil produces a closed circuit Thus, if the coil shown in Fig 71 is shorted, a current will flow in it and produce a magnetic field of its own This will be concentrated in the teeth forming the sides of the slots containing the coil, and may be detected by the drag on a thin piece of iron moved over the core and in contact with it

The test is made by moving a strip of iron over the surface of the armature in the direction from a to b. If the coil shown is short circuited a pronounced drag will be felt as the strip is drawn over the slot in which it rests. After testing in this manner, the armature being turned round. This test is also used for the electro-magnet, and the search with the strip is continued. It may be found necessary to switch off the current to permit the armature being turned round. This test is also used for finding short circuits in wound rotors. It is usually applied only to armatures or rotors having multi-turn coils. Coils for large armatures and rotors are tested more satisfactorily with the 230 volts lamp test already described before being put in their slots.

" DROP TEST " OF ARMATURES.

This test is frequently carried out immediately after the growler test. It is not so successful in locating short-circuits, but will show up faults which the other test will not detect. These are open-circuits and cross-connected coils.

A connection diagram for this test is shown in Fig. 72, where the ring represents the end view of a commutator. A large dry cell of 1½ volts is connected to two widely separated segments such as *a* and *k*.

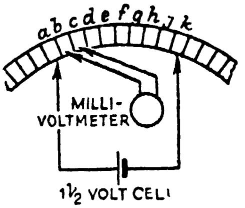


FIG. 72—Drop test of an armature.

Two leads from a millivoltmeter are connected to the segments *b* and *c* and the deflection of the needle noted. They are next connected to *c* and *d*, *d* and *e*, and so on. If the needle of the millivoltmeter comes to rest at the same point in each case the winding is satisfactory. When the needle takes up some other position, or does not show any deflection, the following faults may be present in the coil connected to the two segments under test.

A. If the deflection is in the reverse direction the coil is cross-connected, i.e. the finish lead of one coil is crossed over with the start lead of the next coil but one.

B. If the needle moves rapidly in the correct direction but goes well beyond the point where it has rested for the other coils an open-circuited coil is indicated.

C. A deflection in the correct direction but less than for the other coils indicates a partial short-circuit or a coil with too few turns.

D. No deflection indicates that the coil under test is completely short-circuited.

This test will not indicate a reversed coil i.e. a coil in which the start and finish leads are merely changed over but still connected to the same pair of segments. Such a fault may be detected by the use of a compass moved over the periphery of the core, the faulty coil producing a polarity opposite to those adjacent.

When the drop in volts across each pair of segments has been checked as far as *k*, the battery connection is moved from *a* to say *h*, the other one being moved approximately the same distance. It is not necessary to keep the battery connections the same number of segments apart each time they are moved. If their distance apart is varied each time they are moved, the reading on the millivoltmeter will be different along each section. However, if the original set of readings finished at *j* and *k*, and this reading agreed with all those taken before, these two segments may be taken as the starting pair for the next section. Hence, provided the " drop " across succeeding pairs agrees with the new " drop " across *j* and *k* all those coils must be like *j* and *k*.

In carrying out this test the battery leads are generally pressed on the commutator by the thumb and fingers of one hand. The meter is connected to two suitable pieces of copper wire, insulated from each other and bound together. Their ends are left bare and are pressed on to adjacent segments with the other hand. When large quantities of similar armatures are being manufactured, *e.g.*, in a shop devoted to motors for domestic purposes, it is more convenient to rig up a fixture in which the armatures can be rotated and the current passed into the winding by fixed brushes pressing on the commutator.

This method of testing is not suitable for armatures having large section conductors. Their resistance is very low and the voltage drop too small. In such cases an instrument known as a Ducter is employed. A heavy duty storage cell of two volts supplies the current which is applied to adjacent segments by special holders. These holders contain two sharp pointed steel rods which revolve as they are pressed on to the segments, and in doing so ensure that good contact is made. One point in each holder is used to carry the current to the segment and the other for measuring the potential drop between the segments. Thus the potential drop is measured across the same segments as are receiving current. The reading of the instrument is the actual resistance between the points of contact. It will measure resistances from 1 ohm down to 1 microhm.

TESTING OF FIELD COILS.

Field coils are tested for short circuits by an apparatus of which the diagram is given in Fig. 73. A three-limbed electro-magnet is built up of laminations and excited by alternating current passing through the coil A on the middle limb. The coils B and C are connected so that the e.m.fs. induced in them are in opposition and current does not circulate between them under normal conditions. The coil to be tested is placed over one of the outer limbs. This coil is not connected to any external circuit. If it is satisfactory its presence will not cause any movement of the needle of the milliameter.

A short circuit in this coil will upset the balance of the flux in the limbs and cause a current to flow between A and B and deflect the milliameter needle. A variable resistance is included in the circuit to enable the sensitivity to be adjusted.

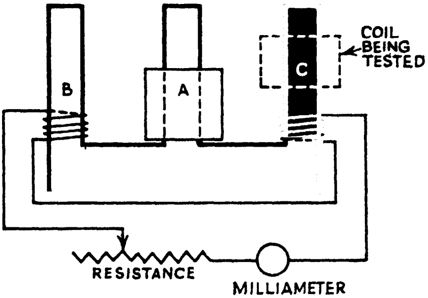


FIG. 73—Transformer test for short-circuits in field coils.

This method of testing is not applicable to coils having metal spools since the spool would behave like a short-circuited turn and cause a deflection of the milliameter needle.

The resistance of all field coils is checked. Since copper wire is permitted to have a variation in resistance of roughly ± 3 per cent (see Table IV in BS. 128), and it may be stretched during the operation of winding the coil, a larger tolerance must be allowed. In general the resistance of field coils is considered satisfactory if within ± 5 per cent of the calculated figure. If it is much higher the coil may contain too many turns or the wire has been stretched too much. If the resistance is more than 5 per cent below, the coil may be short-circuited or have too few turns.

For measuring resistances greater than one ohm a Post Office Box is generally employed. Since this employs only a few volts the voltage drop per turn is very small and shorts will not be indicated unless they are across an appreciable number of turns. The transformer method just described is capable of indicating the presence of a single short-circuited turn in a coil.

A ducter is used for measuring the resistance of heavy strip wound coils of very low resistance. This is accomplished by pressing a pair of points on each end of the coil.

TESTS OF A.C. STATORS.

Small and medium stators are tested for short circuits and other faults by inserting an unwound rotor in them and applying a suitable voltage, usually between two and three times the normal working voltage, to the winding. An ammeter is connected in the supply lead to each phase. The unwound rotor is merely rested on the bottom of the stator bore, it does not have to be rotated.

All three ammeters will indicate the same current if the winding is satisfactory. If not, the fault is found by a process of elimination in most cases.

In a star connected winding an open circuited phase is indicated by no current flowing in the ammeter connected in that phase. With a mesh connection three different currents are shown. Since other causes of failure may exhibit three different readings it is best to proceed with the elimination.

The most usual first step is to leave the voltage on for some time to ascertain if there is a short-circuited coil. Such a coil will heat up and may be felt by the hand, or if left on long enough, it will commence to smoke.

In the absence of a short circuit, the connections of the phases are examined to see if one is reversed, and if satisfactory the resistance of each is measured. A difference in resistance may indicate a coil with too few turns, or in cases where the coils are wound with two or more wires in parallel, one of the wires in a coil may be broken. In the former case the tape must be removed from the end winding and the turns counted. In the latter case each coil in the phase must be disconnected and its resistance checked.

If the resistance of each phase is alike, a reversed coil is probably present. It can only be located by untaping the connections and checking them.

In general the three ammeter test is applied only to stators wound with round wire. Machines having larger section copper are usually bigger and a suitable unwound rotor may not be available. Any faults in these machines are therefore not found until the running test. This is not a serious matter as faults in large machines are very rare.

The tests described in this chapter represent normal practice up to the present. Now, however, the cathode ray oscillograph is being adapted for the purpose. By suitable apparatus such an oscillograph will show all four faults—shorts, open circuits, cross-connected and reversed coils—on a single trace on the screen, if they are present. It may be applied to armatures, rotors and stators, and possibly to field coils.

CHAPTER XXIII

MANUFACTURE OF COMMUTATORS, SLIPRINGS AND BRUSHGEAR

COMMUTATORS.

All commutators, whether they be the tiny ones used in domestic apparatus or those many feet in diameter, and illustrated in Fig. 74, have one thing in common. Unless they are well designed and built they will give endless trouble. Some of the troubles are of mechanical origin. Others may be brought about by faulty insulation or its application and it is this aspect that will be examined.

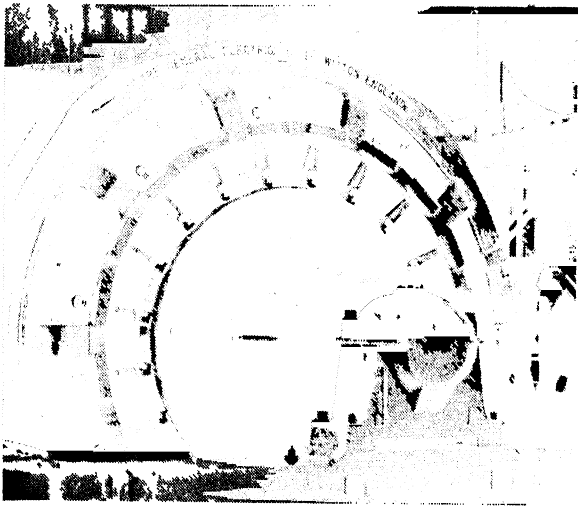


FIG. 74—Commutator and brushgear of a 2,140 h.p (r.m s.) 650 volt 57 rpm. winder motor. (The General Electric Co. Ltd.).

In Fig. 75 is shown a section of a commutator which may be taken as representative of most so far as general principles are concerned. The copper segments A are separated by micanite segments, the whole assembly being held together by the two V-shaped clamp rings B and C. These are insulated from the copper segments by the micanite vee rings D. At the appropriate stage in manufacture the completely assembled commutator is put into a hydraulic press so that the clamping vees are pressed tightly into the copper, and while under compression the nut E is tightened. In small commutators the outer end of the hub is riveted over to hold the clamp ring B. Large commutators are held together by bolts which go through the vee rings and the space between the inner circumference of the segments and the hub on which the structure is built.

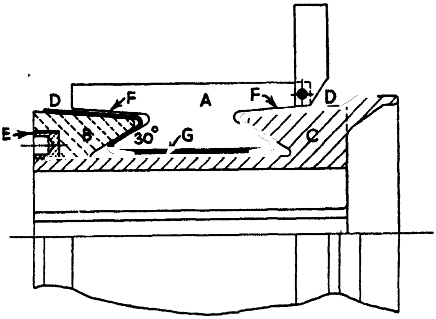


Fig. 75—Section of a typical commutator.

The pressure of the clamp rings on the slopes of the segments causes them to move radially inward until the whole becomes locked as a solid mass. The angle of the slope is usually 30 degs. This type of construction is known as an arch-bound commutator. An important requirement in these commutators is that no mechanical pressure shall exist between the outer slopes F of the micanite vee rings and the adjacent faces in the segments. To ensure this it is usual to design the commutator with a definite slight clearance as shown at F. Alternatively, the slope in the copper may be made 1 deg. greater than that of the vee rings.

There is another construction, known as the wedge-bound commutator, in which the outer slopes make contact just before the 30 deg. slopes come together. This has the effect of causing the segments to move outward a little and the commutator is finally held by the vee rings wedging themselves into the double slope. This type of commutator requires much more careful machining and building and is not used very frequently.

The requirements for the manufacture of good segment and moulding micanite are given in chapter XVII. We have now to examine the methods of applying these products, and will first detail the manufacture of the vee rings. It may be stated in passing that small commutators, up to a few inches in diameter, may have a moulded plastics insulation instead of micanite.

Manufacture of Micanite Vee-Rings.

In general micanite vee rings should be made as thin as possible, since the thicker they are the greater is the difficulty in obtaining commutators which do not give slightly in service due to the bond flowing. Any slight movement resulting in a few high segments, or perhaps ovality, will cause sparking. This complaint invariably grows worse and may necessitate the machine being dismantled after a comparatively short length of service so that the commutator can be re-machined. This fault also causes radio interference.

For most purposes 0.030 in. to 0.040 in. is thick enough for vee rings which are moulded in one piece; the very small ones, up to about 1 in. dia. at the apex being as thin as 0.020 in.

Moulding Vee Rings up to $2\frac{1}{4}$ ins. Diameter.

Vee rings up to $2\frac{1}{4}$ in. dia. at the apex are frequently moulded from discs of micanite. Those of 1 in. dia. and under are produced from micanite washers of suitable diameter. These are heated on a hot plate until the shellac bond is very fluid and transferred quickly to a press. The latter is closed before the bond has time to set. This method produces rings in which the micanite forming the outer slope is somewhat creased.

To reduce the creasing as much as possible those above 1 in. dia. are moulded from discs of the shape shown in Fig. 76. The bottoms of the vee notches coincide with the apex of the finished ring, and the notches are of such an angle that their edges butt in the finished ring. Four discs, each 0.010 in. thick are used for making a ring 0.030 in. thick. They are placed on the top of each other on a hot plate and are staggered so that in the finished ring the joints in one layer do not coincide with those in any other layer. The pressure applied during moulding consolidates the four discs and results in the production of solid, homogeneous rings $\frac{1}{32}$ in thick.

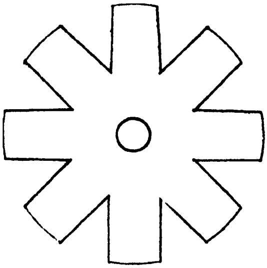


FIG. 76—The shape of micanite discs used for small commutators.

Moulding Vee Rings from $2\frac{1}{4}$ in. to 10 in. diameter.

Larger rings, up to 10 ins. apex dia., are frequently made in the manner illustrated in Fig. 77. Micanite 0.013 in. thick is cut into sectors and slit to form fingers as shown. The slits may be vee-shaped if it is found that overlapping results from the use of parallel slits. This depends upon the width of the slits and the diameter of the ring. The length of the sectors is such that their ends just butt when folded round the plug part of the mould—seen in the background, left of the photograph. They are placed on the top of each other so that the slits are staggered as shown, and their curved edges coincide. (They were placed non-coincident in the photograph so that the staggering was more apparent).

FIG. 77—Stages in the manufacture of micanite vee rings (The General Electric Co. Ltd.).

After heating so that the bond is fluid, the three are placed together around the unheated plug and the fingers bent down the 30 deg. slope. A roughly pre-formed ring, as shown to the right, is thus obtained.

The mould (shown next to the plug) and the plug are then heated up to about 150°C., after this the pre-formed ring is placed in the mould, followed by the plug, which is bedded down by hand. The assembly is then put into a suitable press and left to cool under pressure. To prevent the micanite from sticking, the mould and plug are wiped with a greasy rag, and also lined with mica splittings. A finished ring is shown in Fig. 77 to the right of the mould.

We would like to point out the importance of designing all moulds with a slope to the outer circumference. A slope of 4 or 5 degs. is a great help, both when putting the parts together and when separating them after moulding.

MOULDING OF RINGS ABOVE 10 IN. DIAMETER.

When rings exceed 10 ins. in diameter at the apex it is not convenient to handle the sector type of micanite blanks shown in Fig. 77. It is better to use sanded (milled) sheets of micanite 0.040 in. thick and mould them in segmental lengths as shown at A in Fig. 78. Such mouldings may be from 6 in. to 18 in. in length depending upon the diameter of the commutator. These mouldings are inserted in the machined vees in the copper so that their edges butt.

Two precautions are necessary in applying segmental mouldings. If their ends were cut square, as shown by the front view at B

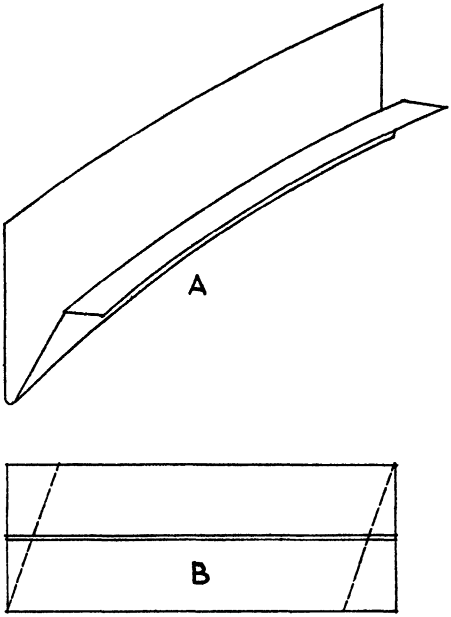


Fig 78—Segmental micanite vee rings

in Fig 78, the butt join would run parallel with the micanite separators between the copper segments and any slight difference between one moulding and the next might result in the uneven seating of the adjacent copper segments in that region To eliminate this possibility the ends are cut off at an angle shown by the dotted lines, so that the joint is spread over three or four segments The second precaution is for electrical reasons Armatures having commutators of this size would be subjected to several tests between windings and earth at upwards of 3000 volts, during their manufacture, and in all probability such a voltage would cause breakdown at the butted joints To obviate this, a second layer of mouldings is placed inside the original one, with their joints midway between those in the first layer These are produced in a mould having slightly different dimensions so that one set fits closely inside the other

There are other methods of applying the micanite, but whatever the method the final result is the same, namely to interpose a solid insulating barrier between the clamp rings and the copper

Inspection of Micanite Vee Rings

It is important that every ring should be throughly inspected A visual inspection will generally suffice for rings up to 3 ins dia., but larger ones and segmental mouldings should also be checked for thickness. The faults to look for are bad distribution of the bond, almost clear or transparent areas, and white opaque areas. Almost transparent areas are due to an excess of mica in that part, the pressure during moulding having caused the bond to flow away. Such a region would take most of the pressure in an assembled commutator, resulting in uneven bedding of the copper segments.

Opaque spots indicate crushed mica, which may disintegrate when rubbed with a finger. Such spots are probably due to an excess of mica taking the sliding pressure exerted during moulding. All these faults probably originate from badly built micanite.

Sometimes rings appear almost clear in a narrow band nearly all the way round, especially near the apex. This is due to the space between the plug and mould not being parallel. Suitable correction should be made to the incorrect part.

Rings struck with a steel rod should emit a hard sound, not a dull one. Experience is necessary to enable one to tell whether a hard sound is due to the ring being well made, or due to an excess of bond. The percentage of bond in a good ring should be 10 to 12 per cent by weight. Whilst this can only be verified by analysis, experienced examiners are able to recognise good rings with a reasonable amount of certainty.

Several measurements of thickness should be made of the 30 deg. slope. A tolerance of ± 0.005 in. from the nominal thickness is usually permissible. Great importance is not paid to variations in the thickness of the outer slope of rings for arch-bound commutators, since the clearance in the commutator should be ample. For wedge-bound commutators, however, the outer slope should comply with the figures already given for the 30 deg. slope.

ASSEMBLING THE SEGMENTS.

The copper segments and micanite separators for large commutators are each sorted out into three groups—nominal thickness, over size and under size. They are then assembled by taking one from each group in turn. This operation is carried out on a flat steel plate, the pieces being stood on end. They are then clamped up, heated, and forced into a retaining ring. For the largest sizes the same rings are used for the original and final clamping. All machining is done while the assembly is in these rings.

Commutator hubs and clamping rings should be designed to prevent the ingress of dust.

The line G in Fig. 75 is the section of a micanite cylinder used to prevent a flash-over from the copper to the hub. It is generally made of a sheet of micanite rolled into a cylinder with an overlapped joint. Its thickness is 30 to 40 mils, and as it is not called upon to take any mechanical stress, except that due to centrifugal force, its make up is not of great importance. In the large bolted type commutators the cylinder is not necessary, but the bolts are insulated by micanite tubes slipped over them.

SEASONING COMMUTATORS.

In high speed commutators there is a possibility of the segments moving outward a little if the micanite softens. To avoid this it is usual to carry out what is known as a seasoning process. Sometimes this is done before the commutator is mounted on its shaft, but the best result is obtained by seasoning after the windings are connected. If the latter method is employed the armature should be heated to about 100°C. before starting the seasoning operation, if heat is to be applied to the commutator by gas flames; otherwise the products of combustion will condense on the cold parts and cause considerable trouble.

The process of seasoning consists of running the armature slowly in a special fixture and heating up the commutator to a temperature in excess of the normal working temperature. It is then run for a short period at a speed in excess of normal, after which it is stopped and the hub clamping nut or bolts are immediately tightened. This cycle may be repeated several times, the idea being to squeeze out as much bond as possible so that the compression is taken by the mica, and also to raise the softening temperature of the bond. If the micanite has been correctly made the bond will not soften enough to flow.

PROTECTION OF THE VEE RING EXTENSION.

The extensions of micanite vee rings beyond the outer faces of the copper are protected against mechanical damage, and perhaps disintegration by windage. For this purpose a string band may be used on commutators up to say six inches in diameter. Larger commutators are protected by cotton, webbing, or glass tape. To ensure adhesion the micanite and the tape are well brushed with shellac varnish and the tape is ironed down with a hot iron. The end of the tape is held by stitching.

SLIPRINGS.

Compared with commutators, sliprings are easy to manufacture. A typical slipring assembly, with brush lifting and short circuiting gear, is shown in Fig. 79.

Three methods are employed for insulating the smaller types of rings from their hubs. They may be held by a synthetic resin moulding, which also encloses the connections to the rings; or the rings may be shrunk on to a synthetic resin paper cylinder pressed on to the hub. A third method is to shrink the rings on to micanite which has been rolled on to the hub and baked at a high temperature to prevent the bond softening and allowing the rings to become loose.

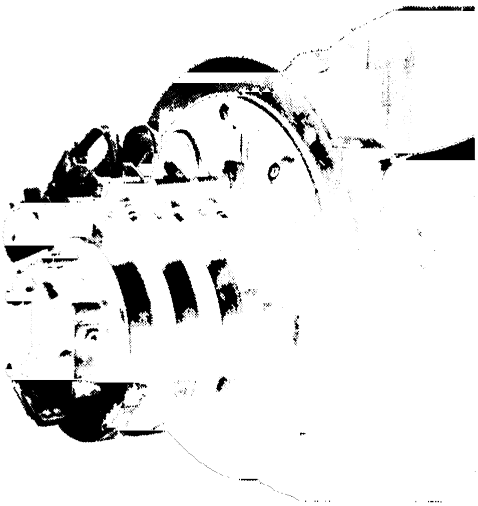


FIG. 79—Slipring assembly.

The use of synthetic resin paper cylinders necessitates working to closer limits than is the case with micanite. This is because the maximum temperature at which the rings can be put on the paper cylinders is not much in excess of 150°C. if the paper insulation is not to be spoilt. With micanite the rings may be heated to well above 200°C., which gives a greater expansion. The insulation on the hub should be as thin as conditions will permit. Generally, a thickness of 0.025 in. for the smaller sizes, up to 0.040 in. for large ones, is found satisfactory for both synthetic resin paper and micanite insulation.

Micanite is invariably used for the hubs of large rings, and special treatment is given to ensure that it is hard. The micanite, which is in the form of a long sheet a little wider than the length of the hub, and about 0.010 in. thick, is softened on a hot plate. The hub is heated and placed on the micanite, which is wrapped on by rolling the hub along the sheet. Five or six thicknesses are applied, and while the bond is still fluid a layer of steel wire is applied under great tension so as completely to cover the surface. It is then baked for several hours at a high temperature. After cooling, the wire is removed, and the micanite is turned in a lathe to the correct diameter for the rings to be shrunk on. When the rings have been fitted and turned, the exposed micanite is protected against damage and disintegration due to windage by a covering of cotton or glass tape. The ends of the tape are held by stitching and the surface rendered as smooth as possible by several coats of an anti-tracking varnish.

In the photograph connectors may be seen passing through the rings. These are insulated with synthetic resin or micanite tubes, the latter being employed for class B insulated machines.

BRUSHGEAR INSULATION.

The use of synthetic resin mouldings (plastics) is shown in Fig. 80. The upper moulding forms the brush rocker for certain fractional horse-power machines. In larger machines, such as those used for general industrial purposes, the rocker is invariably of metal and the insulation is applied to the spindle. One method of doing this is shown by the centre figure. The lower picture indicates how insulation may be applied to brush holders. This is a common form used in domestic apparatus.

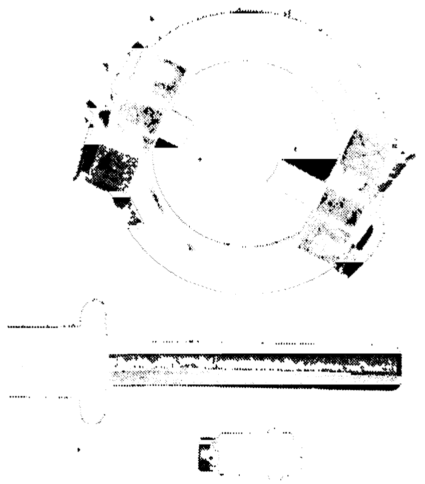


FIG. 80—Application of plastics to brushgear.

The upper component of Fig. 81 illustrates one of many different forms of brush spindle for traction motors. The insulation consists of a square tube of moulded synthetic-resin paper forced on to the square shank of the spindle and seen to the left of the porcelain. The porcelain (shown white), which serves to provide a definite creepage distance to earth, is cemented on the paper tube. The outer end of the square tube is closed with a plug of synthetic-resin paper board, made to fit tightly in the end of the tube and cemented in position.

Micanite is moulded on the shank of the spindle shown on the left. Unless precautions are taken, micanite shrinks with continued service at running temperatures. It should preferably be about $\frac{1}{32}$ in. thick, and in no case exceed $\frac{1}{16}$ in. in thickness for machines working at normal industrial or ship voltages. After the moulded spindle has been given a short bake at 110°C.-120°C. the mould should be tightened up as much as

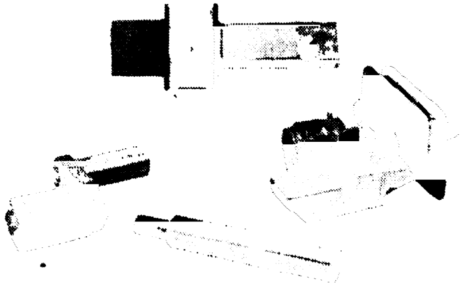


FIG. 81—Various insulations for brushgear.

possible and then baked at 300°C. for half an hour. Upon removal from the oven, the mould should again be tightened and not opened until cold.

The end is sealed with a plug of micanite, and the surface protected with a lapped layer of woven glass or silk tape and shellac varnish.

Should micanised spindles become slack in service they can usually be made perfectly satisfactory by tightening the clamps once or twice while the spindles are at maximum temperature.

The right-hand figure shows the use of synthetic-resin paper board for insulating brush spindles. Synthetic-resin paper tubes are slipped over the bolts. This principle is frequently employed for insulating the brush arms of large D.C. machines of the type shown in Fig. 74. This insulation is class A, but can readily be made class B by using micanite tubes.

The bottom component consists of a synthetic-resin paper tube pressed on to a knurled steel spindle, the knurling being parallel with the axis of the spindle. It is a very useful brush spindle for the smaller sizes of industrial machines, both D.C. and A.C.

CHAPTER XXIV

FRACTIONAL HORSE-POWER MACHINES

There are many types of fractional horse-power machines. There is the straight D.C. type which will only run on direct current; the universal type which will work on both A.C and D.C. current; various types of single phase motors, and also three phase motors.

For purposes of studying how these may be insulated, the whole series may be divided into two groups, those with a D.C. type of winding, in which is included the universal type, and those with windings of an A.C. type.

WIRE COVERINGS.

With such diverse types and sizes of machines it is natural that many kinds of wire covering are employed. The increasing availability of synthetic enamelled wire will, no doubt, result in many of the coverings which had to be used in the past becoming obsolete. This particularly refers to single- and double-silk, enamel-silk, enamel and paper, and single- or double-cotton coverings.

In view of this impending change it will be a good thing to record briefly the uses made of these various coverings. Anybody with experience in using them will know how frail and troublesome some were.

Silk covered, enamelled and enamel and silk covered wires, owing to their thin covering, have been in favour for the smaller sizes of machines, chiefly for armatures and field coils.

In Fig. 82 two methods of winding armatures are shown. Former wound coils are employed in the armature on the left. These may be of any type of textile covered wire, but not ordinary enamelled wire. The only satisfactory manner in which an armature can be wound with ordinary enamelled wire is to rotate it about its shaft and feed the wire into the slots as shown in the machine on the right.

Double enamelled wire may be used for small stators, but needs careful handling if short circuits are to be avoided.

In larger F.H.P. machines, either D.C. or A.C., fine d.c.c. proved the most reliable covering until the arrival of the synthetic enamel covering.

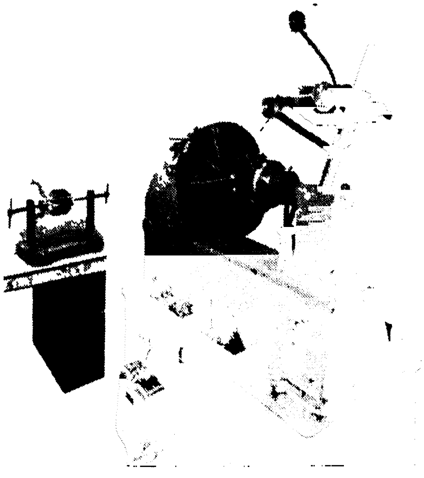


FIG. 82—Two methods of winding small armatures.

DIRECT CURRENT TYPES.

Under this heading are included the plain D.C. and the universal types.

Fig. 83 is a longitudinal section of an armature wound with formed coils and Fig. 84 one in which the wire is wound direct into the slots. Corresponding slot sections also are shown. In the former the slot trough is of varnished cotton cloth stuck to presspaper, sometimes known as composite slot insulation and described in chapter XX. In the latter the insulation components are employed separately.

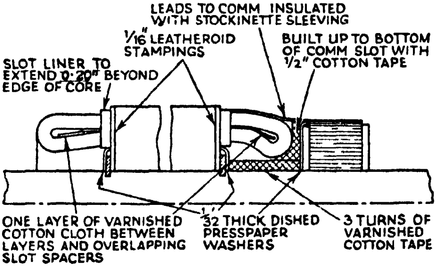

LEADS TO COMM INSULATED WITH STOCKINETTE SLEEVING
1/16" LEATHEROID STAMPINGS
BUILT UP TO BOTTOM OF COMM SLOT WITH 1/2" COTTON TAPE
SLOT LINER TO EXTEND 0·20" BEYOND EDGE OF CORE
ONE LAYER OF VARNISHED COTTON CLOTH BETWEEN LAYERS AND OVERLAPPING SLOT SPACERS
1/32" THICK DISHED PRESSPAPER WASHERS
3 TURNS OF VARNISHED COTTON TAPE

FIG. 83—Section of an armature wound with formed coils.

The two sections in Fig. 85 show how small field coils may be insulated. If the coils are very small varnished silk or rayon may

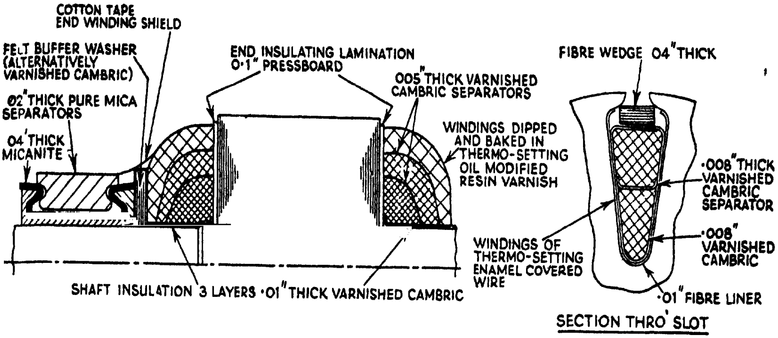

COTTON TAPE
END WINDING SHIELD
FELT BUFFER WASHER (ALTERNATIVELY VARNISHED CAMBRIC)
·02" THICK PURE MICA SEPARATORS
·04' THICK MICANITE
END INSULATING LAMINATION 0·1" PRESSBOARD
·005" THICK VARNISHED CAMBRIC SEPARATORS
WINDINGS DIPPED AND BAKED IN THERMO-SETTING OIL MODIFIED RESIN VARNISH
WINDINGS OF THERMO-SETTING ENAMEL COVERED WIRE
SHAFT INSULATION 3 LAYERS ·01" THICK VARNISHED CAMBRIC
FIBRE WEDGE ·04" THICK
·008" THICK VARNISHED CAMBRIC SEPARATOR
·008" VARNISHED CAMBRIC
·01" FIBRE LINER
SECTION THRO' SLOT

Fig. 84—Section of an armature with wire wound direct into the slots.

be used in place of the varnished cambric shown in the left section, and a piece of varnished pressboard interposed between the coil sides and the pole.

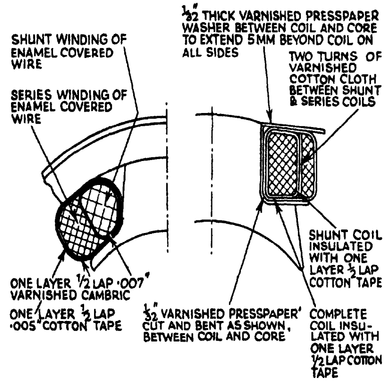

SHUNT WINDING OF ENAMEL COVERED WIRE
SERIES WINDING OF ENAMEL COVERED WIRE
ONE LAYER ½ LAP ·007" VARNISHED CAMBRIC
ONE LAYER ½ LAP ·005" COTTON TAPE
1/32" THICK VARNISHED PRESSPAPER WASHER BETWEEN COIL AND CORE TO EXTEND 5MM BEYOND COIL ON ALL SIDES
TWO TURNS OF VARNISHED COTTON CLOTH BETWEEN SHUNT & SERIES COILS
SHUNT COIL INSULATED WITH ONE LAYER ½ LAP COTTON TAPE
1/32" VARNISHED PRESSPAPER CUT AND BENT AS SHOWN, BETWEEN COIL AND CORE
COMPLETE COIL INSULATED WITH ONE LAYER ½ LAP COTTON TAPE

Fig. 85—Two methods of insulating field coils of Fractional H.P. machines.

For larger types of F.H.P. machines micanite insulation is specified for some purposes, especially for use on board ship. Diagrams showing how micanite is used are reproduced in Fig. 86. The inner slot liner of 0.2 mm (0.008 in.) presspaper is required for enabling the coils to be fed through the slot opening.

Alternating Current Types.

These comprise several types. Some have single phase windings with an auxiliary winding for starting. Others have three phase windings which may be of the single layer, or the two layer type.

A single phase type of winding is depicted in Fig. 87. The coils are wound on formers and inserted into the slots a few turns at a time. Double enamel or synthetic enamelled wire is useful for

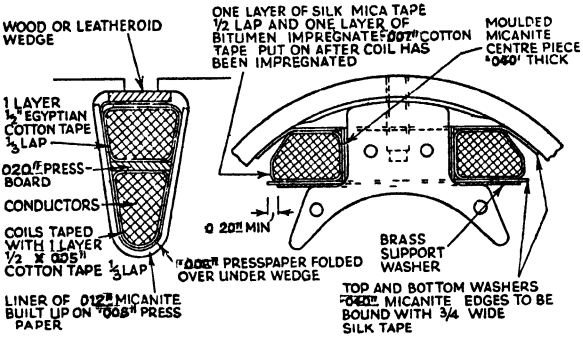

WOOD OR LEATHEROID WEDGE
ONE LAYER OF SILK MICA TAPE ½ LAP AND ONE LAYER OF BITUMEN IMPREGNATED ·007" COTTON TAPE PUT ON AFTER COIL HAS BEEN IMPREGNATED
MOULDED MICANITE CENTRE PIECE ·040" THICK
1 LAYER ½" EGYPTIAN COTTON TAPE ⅓ LAP
020" PRESS-BOARD
CONDUCTORS
COILS TAPED WITH 1 LAYER ½ × 005" COTTON TAPE ⅓ LAP
0 20" MIN
·008" PRESSPAPER FOLDED OVER UNDER WEDGE
BRASS SUPPORT WASHER
LINER OF 012" MICANITE BUILT UP ON ·008" PRESS PAPER
TOP AND BOTTOM WASHERS ·040" MICANITE EDGES TO BE BOUND WITH ¾ WIDE SILK TAPE

Fig 86—The use of micanite insulation in Fractional H P machines

these coils Owing to the high electric strength of the enamel it is possible to use simple troughs of 12 or 15 mils varnished presspaper as shown in the section in Fig 88 Similar material is fixed between the end winding portions of the coils where they come close together The wedges may be of wood, leatheroid or synthetic-resin paper board

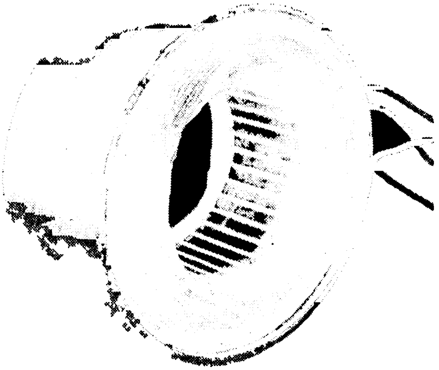


Fig 87—Stator winding of a single-phase F H P motor (The British Thomson-Houston Co Ltd)

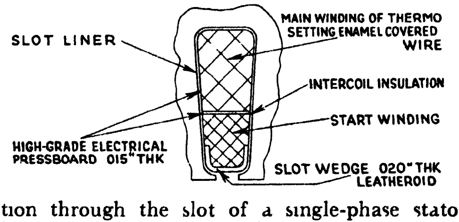

SLOT LINER
MAIN WINDING OF THERMO SETTING ENAMEL COVERED WIRE
INTERCOIL INSULATION
START WINDING
HIGH-GRADE ELECTRICAL PRESSBOARD 015" THK
SLOT WEDGE 020" THK LEATHEROID

Fig 88—Section through the slot of a single-phase stator, containing both main and starting windings

A three phase stator winding of the single layer type is shown in Fig. 89. Paper and enamel insulated or synthetic enamelled wire is suitable for these windings. The slot trough may be of the varnished-cloth presspaper variety (12 mils thick) or of 12 or 15 mils varnished presspaper. In spite of the good electric strength of the covering it sometimes fails when a pressure test of 1500 volts is applied between phases during manufacture. For this reason the coils are reinforced with one layer of cotton tape. The coil leads are insulated by a length of varnished cotton sleeving slipped over them.

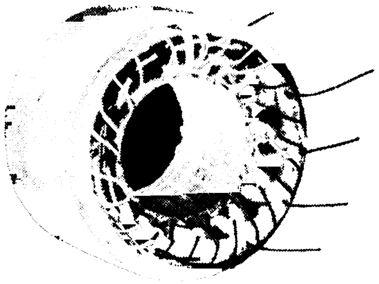


Fig. 89—Stator winding of a three-phase F.H.P. motor. (The General Electric Co. Ltd.).

In motors approaching the one horse-power size a two layer winding is sometimes employed. Mica-presspaper troughs may also be used, especially with textile covered wire. With this type of winding there may be the full phase voltage between the two half coils in a slot. It is therefore important to ensure that the two are well insulated from each other. A method of doing this is shown in Fig. 90 where a separate inner liner surrounds the upper half coil. The insulation between coils in the end winding may be provided by taping, or suitably shaped pieces of varnished presspaper may be inserted between them.

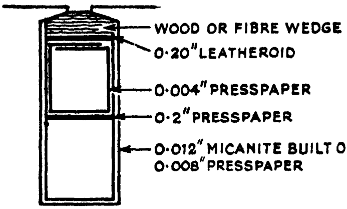


Fig. 90—Slot insulation for a three-phase F.H.P. motor winding.

TESTS DURING MANUFACTURE.

Armatures are tested for open and short-circuits after the leads have been put in the commutator tags, after being soldered, and again after impregnation and finishing off ready for assembly. The resistance of field coils is checked before they are taped or impregnated, and after completion.

Stators are checked for open- and short-circuits after all connections are made and before impregnating. The test is repeated after impregnation.

High-voltage tests are based on Table 29 which has been extracted from BS. 170-1939. They are invariably in the nature of "flash tests," *i.e.*, the voltage is applied for only a few seconds. In general the test is applied to armatures and stators after the windings are finished ready for impregnation; the voltage is 500 volts above the appropriate figure in the table.

Table 29.—Test Voltage for Fractional Horse-Power Machines.

Item number	Description of machine	Test-voltage (r.m.s.)
		Volts
1	For all machines wound for 50 volts or less.	500
2	For machines wound for voltages higher than 50 volts up to and including 250 volts.	1000
3	All machines wound for more than 250 volts.	1000 plus twice rated voltage.

FINAL HIGH-VOLTAGE TESTS.

These should be in accordance with Table 29. The Specification stipulates that the appropriate voltage should be applied only to a new and completed machine in normal working condition with all its parts in place and, unless otherwise agreed, shall be carried out at the Manufacturers' Works, preferably at the conclusion of the temperature test of the machine. It is to be applied between the windings and the frame of the machine. The duration of the test shall be not less than 5 seconds for machines of continuous ratings up to and including $\frac{1}{3}$ h.p. per 1000 r.p.m. or 250 watts or VA per 1000 r.p.m. and not less than 1 minute for larger machines. The voltage is to be alternating at any frequency between 25 and 100 cycles per second.

The insulation resistance should be not less than 1 megohm at 500 volts D.C. This test is invariably carried out with a 500 volts megger.

CHAPTER XXV

INSULATION IN DIRECT CURRENT MACHINES

(Excluding those for Fractional Horse-Powers)

ELECTRICAL CONDITIONS IN ARMATURES.

In order to understand why the insulation is disposed in the various ways to be described, some knowledge of the electrical conditions is necessary. The first point, and a most important one, is that the passage of electric current along conductors causes them to heat up, and this heat must be dissipated. Insulation impedes the passage of heat away from the conductors, hence it is policy to keep the insulation as thin as possible, consistent with electrical safety.

ELECTRICAL SAFETY OF ARMATURE WINDINGS.

Electrical safety is a condition which must be provided for as a long term policy. It does not only mean that a machine shall be insulated well enough to stand up to the high voltage tests at the manufacturers' works, but that it shall give unfailing service for fifteen or twenty years; the two requirements necessitate entirely different treatment. For example a machine insulated just sufficiently to withstand the high voltage tests might give unfailing service for years if run in a clean power station or workshop. On the other hand, a traction motor or steel mills motor insulated with the same idea in mind would probably breakdown in the course of a few weeks, due to moisture or metal dust penetrating the windings and providing the conditions for short circuits or breakdowns to earth. In such cases the ideal of using as little insulation as possible cannot be attained. The windings must be completely encased with ample insulation, so that, for a given temperature rise a larger machine may be necessary for a given output than would be required for normal industrial service.

The next point is one which few, excepting designers, seem to understand. In Fig. 91 is shown diagramatically the commutator end of an armature winding in which there are three commutator segments per slot. In general the voltage between adjacent segments is limited to between 10 and 20 volts, seldom more. Thus the voltage between the sides of the coils connected to a and b is only that between the adjacent segments a and b.

Because the coils are taped overall many people think that there is full voltage between them, and that additional insulation, such as a layer of mica or varnished cotton tape ought to be added It will be seen that this is a fallacy The tape is chiefly employed in the end winding to keep the turns from becoming disarranged In fact, if each coil is composed of taped strips as in Fig 95 it is quite common for the separate strips to go independently to the commutator, without each slot group being taped together

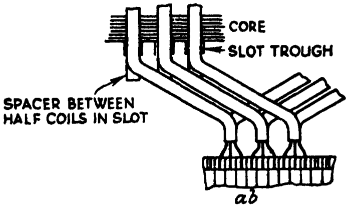


Fig 91—Armature connections—lap winding

Armature Coils of Round Wire.

These coils are invariably taped all over and such an operation inevitably results in the coils taking up a circular shape in cross section. Before they can be inserted in their slots they have to be flattened along the sides. This generally causes some of the turns to alter their relative position. If the taped group contains three sections, *i.e.*, there are three independent coils, each of which will be connected to a pair of segments, it is possible to have wires coming together with the voltage between them equal to that across three segments. It is therefore important not to treat the coils brutally when flattening them or the insulation on the wire may be damaged and will not stand up to the comparatively high-voltage which may exist across several commutator segments.

This danger does not exist when rectangular or square conductors are employed since coils of this kind retain their shape whilst being taped.

Electrical Conditions in Armature Slots and End Windings.

In the slots there is the full line voltage between the two half coils. For this reason, the insulation between them is reinforced by the use of a spacing strip. If the coils are taped this serves to reinforce the covering on the conductors, in which case the strip may be only 20 or 30 mils thick. When taped conductors are employed the overall taping is often dispensed with and the separating strip is made 40 or 60 mils thick. The separating strips should always be carried beyond the bends at the end of the slot portions of the coils since the electric strength of the taping is weakest at those points.

Consideration of Fig. 91 also shows that as the upper part of a coil progresses away from the bend towards the nose (*i.e.*, the outer end) the voltage difference between it, and the coils which cross beneath it becomes smaller. It is necessary to interpose insulation between the two layers where the voltage is high, and since such insulation must be kept in place it is usual to make it extend from under the separating strips to the start of the radius at the nose, as shown in Fig. 93. It is not taken closer to the core because the space between the coils where they emerge from the slots up to the bends, is kept open for ventilating and cooling. In any case it cannot be fixed closer to the core than the outer edges of the troughs.

The slot insulation is extended outside the slot for a distance of ⅜ in. to ⅝ in., depending upon the size of the machine. In large machines where finger strips are employed for preventing long core teeth from spreading longitudinally, the slot extension is made at least 1 in.

When coils have more than one turn per commutator segment it is usual to reinfore the leads to the commutator with cotton sleeving, generally called stockinet. In addition, tape is sometimes interwoven between them.

Figure 91 represents a lap winding. This does not present much difficulty as the leads do not leave the coil excepting at or near the nose. In the cases of wave windings, however, they leave the coils at the bends and cross over the other coils as shown in Fig. 92. This results in high voltages being present between

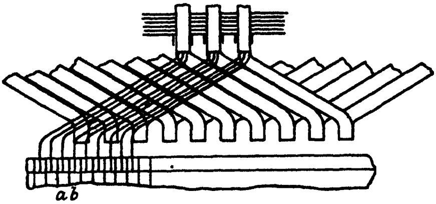


FIG. 92—Armature connections—wave winding.

the leads and the coils—the case is somewhat analogous to that existing between the two layers of coils—and a solid barrier, as shown in Fig. 93 is interposed between leads and coils.

It is necessary to provide ample insulation between the coils and the armature core, also between the end windings and any metal in close proximity. The methods of accomplishing the latter are clearly shown in Fig. 93 and need no amplification beyond saying that in the smaller armatures the mica-presspaper may be replaced by a combination of presspaper and varnished cotton (empire) cloth, or two or more pieces of varnished presspaper.

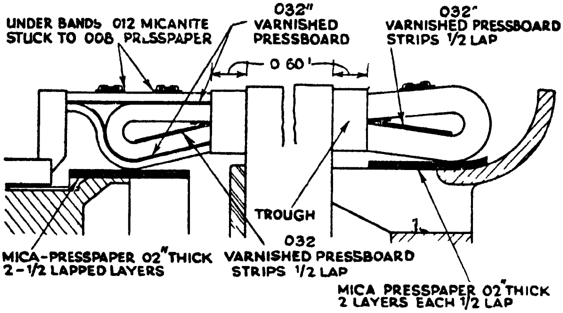

UNDER BANDS 012 MICANITE STUCK TO 008 PRESSPAPER
032" VARNISHED PRESSBOARD
032" VARNISHED PRESSBOARD STRIPS 1/2 LAP
0 60"
TROUGH
032 VARNISHED PRESSBOARD STRIPS 1/2 LAP
MICA-PRESSPAPER 02" THICK 2-1/2 LAPPED LAYERS
MICA PRESSPAPER 02" THICK 2 LAYERS EACH 1/2 LAP

Fig 93— Disposition of insulation in typical medium sized armature

Conductor and Slot Insulation

Conductor and slot insulation varies greatly and a selection of the most general types will now be described It should be understood that many of the applications described in these chapters are not the speciality of any one manufacturer but represent the general practice of the industry

In Fig 94 is shown a useful type of insulation The coils may be wound with round wire or rectangular strip insulated with d c c , synthetic enamel, asbestos or double glass At present synthetic enamel is applied only to round wires If the slot liner is of mica-presspaper or other composition containing a reasonable amount of mica it may be regarded as Class B insulation

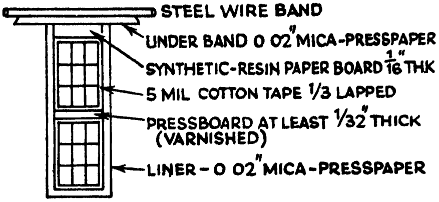

STEEL WIRE BAND
UNDER BAND 0 02" MICA-PRESSPAPER
SYNTHETIC-RESIN PAPER BOARD 1/16" THK
5 MIL COTTON TAPE 1/3 LAPPED
PRESSBOARD AT LEAST 1/32" THICK (VARNISHED)
LINER - 0 02" MICA-PRESSPAPER

Fig 94—Slot insulation of typical medium sized armature

When the coils are held in by steel wire bands it is advisable to maintain a reasonable creepage distance from the coils to the top of the slots by inserting a $\frac{1}{16}$ in closing strip at the top, as shown

Creepage Distance

The term "creepage distance" is rather an ambiguous one as applied to electrical machines It is normally associated with the distance a current would have to travel to get from a point of high potential to one of lower potential by creeping or flashing over the intervening surface As an example may be cited the distance from the outer vertical surface of commutator segments across the micanite vee ring extension to the metal clamp ring.

In machines the term is also applied to the distance from points of weakness in an insulating covering to the nearest earthed part. Thus, referring to Fig 93 since the coils are only taped with cotton tape and varnished, the electric stress between the conductors and the top of the armature teeth, especially during the high voltage test, might be great enough to puncture the tape if the coil were too near the top of the slot. It is for a similar reason that the slot troughs, or micanite tubes, if used, are extended beyond the slot, the length of the extension increasing with increased voltages.

The high voltage test is not the only time of danger. Machines invariably accumulate dirt on their windings as time passes. If this is metallic, or carbon from the brushes, a path of comparatively low resistance is provided. Even dirt which does not contain these ingredients becomes partially conducting if a machine becomes damp due to "sweating" in damp weather. When the coils are held in by wedges, as shown in Fig. 95 the liner is invariably folded over under the wedge. In large machines the slot insulation invariably contains mica, even though the insulation is specified as class 'A' the other alternatives given above not being considered sufficiently reliable. Micanite-presspaper liners of this type have an electric strength of 6000 volts, and at least 2000 volts are required to cause a breakdown between adjacent conductors.

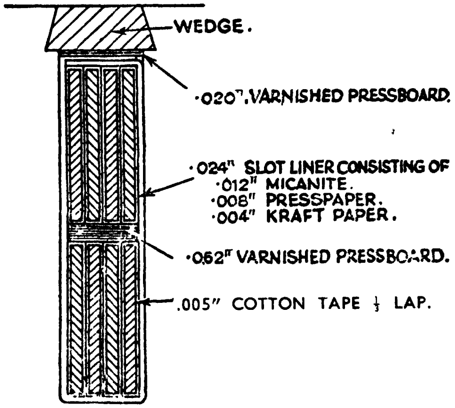

WEDGE.
·020" VARNISHED PRESSBOARD.
·024" SLOT LINER CONSISTING OF
·012" MICANITE.
·008" PRESSPAPER.
·004" KRAFT PAPER.
·062" VARNISHED PRESSBOARD.
.005" COTTON TAPE ½ LAP.

FIG. 95—Slot insulation for large armatures.

The conductors shown in Fig. 96 are uninsulated copper strips, the insulation being provided by mica sandwiched between .002 in. kraft paper, a flexible mica sticking varnish being used. The electric strength between conductors is in the region of 2000 volts and to earth about 9000 volts.

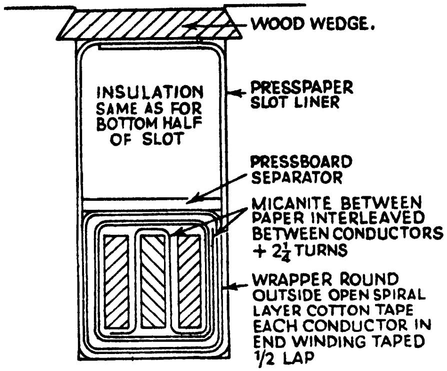

WOOD WEDGE.
INSULATION SAME AS FOR BOTTOM HALF OF SLOT
PRESSPAPER SLOT LINER
PRESSBOARD SEPARATOR
MICANITE BETWEEN PAPER INTERLEAVED BETWEEN CONDUCTORS + $2\frac{1}{4}$ TURNS
WRAPPER ROUND OUTSIDE OPEN SPIRAL LAYER COTTON TAPE EACH CONDUCTOR IN END WINDING TAPED ½ LAP

FIG 96—The use of mica-paper for combined conductor and slot insulation

The arrangement depicted in Fig 97 has an electric strength of about 1000 volts between conductors If the tube is made of micafolium the electric strength to earth will be in the region of 15000 volts for a wall thickness of 0 030 in Micafolium consists of mica splittings stuck to kraft paper If jap tissue or flexrope paper be used a greater proportion of mica can be incorporated and an electric strength of 20000 volts is quite usual

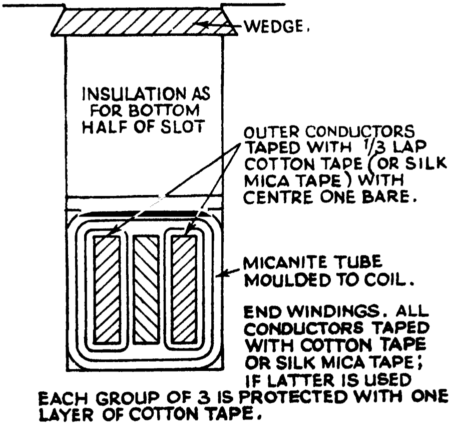

WEDGE.
INSULATION AS FOR BOTTOM HALF OF SLOT
OUTER CONDUCTORS TAPED WITH ⅓ LAP COTTON TAPE (OR SILK MICA TAPE) WITH CENTRE ONE BARE.
MICANITE TUBE MOULDED TO COIL.
END WINDINGS. ALL CONDUCTORS TAPED WITH COTTON TAPE OR SILK MICA TAPE; IF LATTER IS USED EACH GROUP OF 3 IS PROTECTED WITH ONE LAYER OF COTTON TAPE.

FIG. 97—Mica-paper moulded to form a tube on the slot portion of an armature coil.

There are other variations but enough has been said to show how insulation may be applied to armature coils. One warning should be given. It is inadvisable to use tape, whether mica or varnished cotton, as the sole insulation to earth. With the few number of layers for which there is room there is a possibility of creepage between the overlaps leading to failure. A more impenetrable barrier, such as varnished pressboard of adequate thickness, or a couple of turns of mica-paper in sheet form should be used.

Another point to be remembered is that although bare conductors may be permissible in the slots, e.g., as shown in Fig. 96, every one should be individually insulated in the end winding. It is found that the movement and bending which the end winding receives, during winding, banding, and in service results in shorts developing if every conductor is not insulated.

EQUALISING CONNECTIONS.

These are frequently used in lap-wound armatures. They are of two general types: they may be of the evolute type, having an appearance similar to the back end of an armature winding, or they may consist of rings of copper strip from which connections are taken to appropriate armature conductors.

A method of insulating the evolute type is shown in Fig. 98 the strips themselves being insulated with cotton tape or mica tape protected with cotton tape, depending upon the class of insulation.

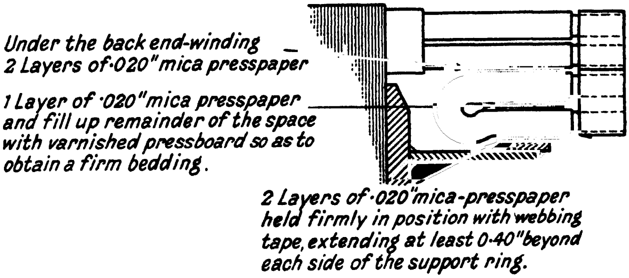

Under the back end-winding
2 Layers of·020"mica presspaper
1 Layer of ·020"mica presspaper and fill up remainder of the space with varnished pressboard so as to obtain a firm bedding.
2 Layers of ·020"mica-presspaper held firmly in position with webbing tape, extending at least 0·40"beyond each side of the support ring.

FIG. 98—Insulation of equaliser connections in an armature.

In the ring type the connections, or tappings, by which name they are frequently known, may be insulated with varnished cotton tape held in position by the cotton tape which is used for taping the rings.

The rings may be separated with varnished pressboard, the thickness being enough to avoid pressure at the tappings. The idea is shown in Fig. 99.

Assembled rings are frequently insulated with mica presspaper

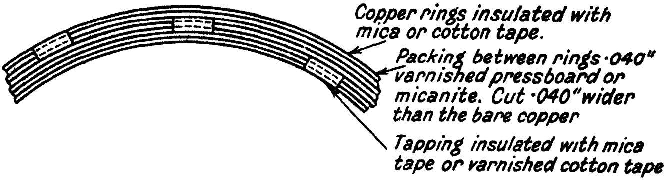

Copper rings insulated with mica or cotton tape.
Packing between rings ·040" varnished pressboard or micanite. Cut ·040"wider than the bare copper
Tapping insulated with mica tape or varnished cotton tape

FIG. 99—Insulation of equalising rings for an armature.

where they will make contact with their metal supports, they are then taped all over with cotton tape, dried out, given a long immersion in impregnating varnish and baked.

If they have to be for Class B machines the insulation is modified in the manner already indicated for Class B armatures.

MILL TYPE AND TRACTION ARMATURES.

These are frequently insulated with Class B insulation and have fibrous glass or asbestos covered conductors. As already suggested these two types of machine need protection against very adverse conditions. Of the two the traction machines experience the worst conditions because moisture is sprayed on to them from the wheels of the vehicles, and these motors are seldom totally enclosed. The type of motor used in Steel Mills is illustrated in Fig. 100. It will be noticed that protection is provided against metal dust getting into the windings by completely enclosing them, shrouds of cotton or asbestos cloth being fitted over the end windings Fig 101 is a photograph of a traction armature; the protection is completed by a hood of glass or asbestos fabric which completely encloses the rear end winding and a covering of the same material over the front end winding.

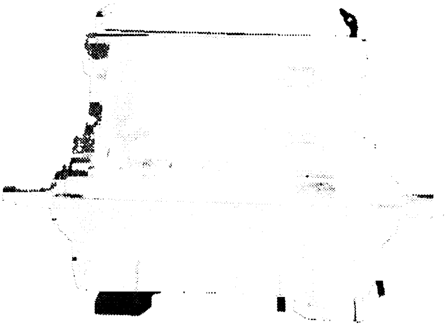


FIG. 100—Motor for steel mills. 60 h.p 250 volts. (The English Electric Co Ltd)

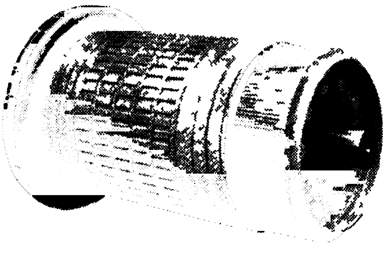


FIG. 101—Railway motor armature, 328 h p. Insulated for 1,500 volts. (The General Electric Co. Ltd.).

GLASS INSULATED ARMATURES.

The manufacture of these presents no serious trouble once the technique has been mastered. The special mica sticking and impregnating varnishes require higher temperatures and longer times for their curing.

Fibrous glass insulation on wire or strip is more readily fractured than cotton covering. If tension has to be applied during the winding of the coils it should not be done by passing the wire or strip through split clamps of fibre; the only safe way is to apply a brake to the drum of wire.

Coils of glass covered wire or strip may be taped with 3 mil woven glass tape, then dried out and immersed in a suitable varnish.

If the conductors are of too large a section for covering in the lapping machines they may be taped, either with 4 mil varnished glass tape or 3 mil woven tape. In the latter case they should be dried out, immersed in varnish and lightly baked.

Figure 102 is reproduced from a photograph of a generator insulated entirely with mica, glass and high temperature varnish. It is one of a large number made for service at 140°C. Details of the field insulations are described under the appropriate headings.

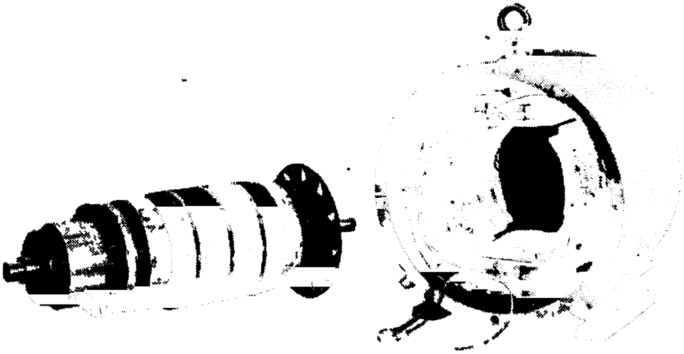


FIG. 102—D.C. Generator insulated only with fibreglass, mica, and high-temperature varnish. For service at 140 deg. C. (The General Electric Co. Ltd.).

MAIN FIELD AND INTERPOLE COILS FOR INDUSTRIAL MACHINES.

There are two main types of coils for industrial machines, those that are taped all over, and those that are not taped. For the former, single or double cotton, glass or asbestos covered wire is employed. The wire for untaped coils may have any of these coverings or ordinary enamelled wire may be used.

Taped Coils.

Taped coils must be wound on formers, tapes being interleaved in the layers to hold the winding together. Flexible micanite washers 0.030 in. thick, are placed at the top and bottom of the coil after it has been removed from the former. These are made larger than the coil faces so that they can be bent about ½ in. down the outside to give ample creepage to earth.

A similar thickness of micanite is used for lining the inside of the coil. This is made about one inch longer than the distance between the flat faces, it is then cut down at each corner to permit ½ in. being folded over on to the washers. Separate small pieces of flexible micanite are fitted in each corner to cover over the small gaps present where the centre micanite bends outward. A piece of 0.030 in. presspaper is fixed inside the coil as mechanical protection to the micanite. The whole coil is then taped all over with 7 mil cotton tape and impregnated in compound. Interpole coils may be insulated in the same manner.

Untaped Coils.

A photograph of a field system with untaped coils is shown in Fig. 103. The main coils are wound with enamelled wire, and the interpole coils with d.c.c. The spools for both are made of pressboard, those for enamelled wire coils being impregnated in varnish before any wire is wound on them. Those for the interpoles need not be varnished as the wound coils are impregnated in compound.

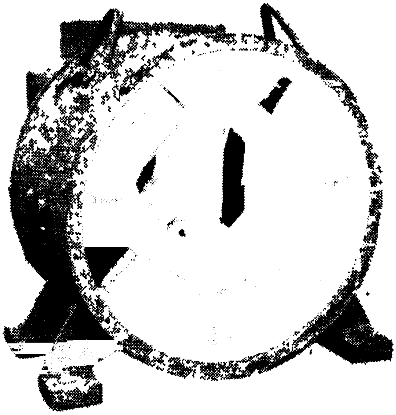


Fig. 103—Typical industrial motor field assembly employing untaped coils. (The General Electric Co. Ltd.).

Tapes are interleaved in the windings and brought over the flanges to keep them in position. The flanges vary in thickness from 0.040 in. to 0.080 in. according to the size of the coils. The centres of the spools are formed of 0.060 in. pressboard.

For machines having armatures of larger diameter than about 6 ins. it is advantageous to support the insulation with a thin sheet iron or brass spool.

It will be appreciated that there is necessarily a narrow space between the centre insulation and the flanges. To prevent creepage through this space it may be closed by taping $\frac{1}{8}$ in. dia. rope to the corner turns of the first layer of wire, the rope fitting into the angles formed by the junction of the centre and flanges. Alternatively, a suitable thickness of thin twine may be wound in the corners and well brushed with shellac varnish.

If the coils are for very large machines, and wound with rectangular wire, the necessary protection may be provided by taping the corner turns of the first layer with varnished cotton tape, and protecting it with 5 mil cotton tape.

Bare Strip Coils.

When the section of copper for interpole coils is too large for covering with cotton, i.e., if it is much more than $\frac{3}{8}$ in. wide, means have to be found for employing bare copper strip and insulating the turns. One method of insulating strip on edge coils is depicted in Fig. 104. Varnished pressboard troughs 0.030 in. thick are fitted to alternate turns. Alternatively washers may be used between turns if preferred. These must be cut at one side for inserting in the spiral. Since a cut may open and permit a short circuit between turns, it is usual to employ two washers of say 0.015 in. thickness, inserted with the cuts on opposite sides of the coil. The centre and flanges may be of pressboard as before.

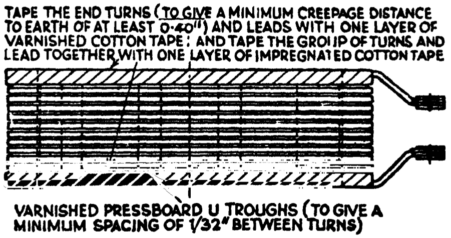

TAPE THE END TURNS (TO GIVE A MINIMUM CREEPAGE DISTANCE TO EARTH OF AT LEAST 0·40") AND LEADS WITH ONE LAYER OF VARNISHED COTTON TAPE: AND TAPE THE GROUP OF TURNS AND LEAD TOGETHER WITH ONE LAYER OF IMPREGNATED COTTON TAPE
VARNISHED PRESSBOARD U TROUGHS (TO GIVE A MINIMUM SPACING OF 1/32" BETWEEN TURNS)

Fig. 104—Insulation for strip-on-edge interpole coils.

Sometimes the coils are wound with the strip on the flat, in which case lengths of 8 to 10 mil varnished presspaper, cut a little wider than the copper, are fed in as the winding proceeds.

These forms of construction are applicable to all sizes of machine, including those having an output of many hundreds of horsepower or kilowatts.

If class B insulation is required micanite and other suitable material may be used in place of pressboard. A form of synthetic resin board, built of sheets of asbestos paper, makes a good material for coil flanges. Seven mils asbestos paper impregnated in varnish is suitable for winding in between the turns of strip-on-the flat coils.

GLASS INSULATED FIELD AND INTERPOLE COILS.

Glass insulated wire and strip may be used if obtainable; in general it may be said that strip wider than $\frac{3}{8}$ in. does not cover very well, the yarn tends to open out and in wider strip the copper may become exposed.

It is rather difficult to produce hard washers composed of mica-glass, and in consequence designs have to be based on the use of non-rigid insulation. For this reason flexible mica-glass and taped coils are often employed.

The use of fairly thick varnished glass tape, say 8 mils thick, between the turns of strip-on-the flat coils provides a reliable type of insulation for the purpose.

MILL TYPE AND TRACTION MACHINES.

All coils are completely enclosed in insulation. Often the wound coils are taped overall with cotton or glass tape, brushed with synthetic resin varnish and bakelised before the overall insulation is added. This may consist of cloth-mica tape, or the straight sides and ends may be wrapped with micafolium and the corners taped with silk-mica tape overlapping on to the wraps. The outside tape may be of asbestos or woven glass. The space inside these machines is generally very limited and the coils in consequence are usually given a final pressing in suitable moulds after all taping is finished. This accounts for the clean-cut appearance of such coils.

Figure 105 is included for the purpose of showing the care taken to exclude dirt and moisture from every part of the winding. The connections entering the coils are bulky because they are liberally coated with an insulating putty before being taped up. Some of the putty is squeezed out by the tape and helps to seal between the layers.

TESTS DURING MANUFACTURE.

Armature coils of more than one turn may be tested for short circuits on the transformer described in chapter XXII. Before the windings of industrial type machines are assembled in the core, the commutator is flash tested at 3500 volts to earth. A flash test is one applied for about 10 seconds.

After assembly in the core and connection to the commutator, the winding is generally flash tested to earth at 500 volts above the final high-voltage test value. A further test at this figure is made when the armature is finished and ready for sending to the assembly department. This test lasts for one minute when applied to large armatures, but for small ones it takes the form of a flash test.

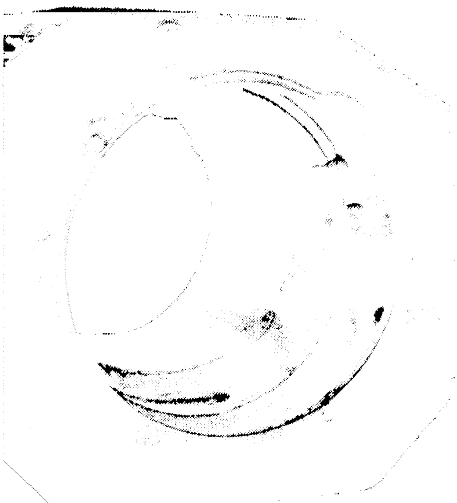


FIG. 105—Field system of 328 h.p. railway motor insulated for 1,500 volts. (The General Electric Co. Ltd.).

Drop tests are taken after soldering the commutator connections, and after completion of the armature.

Field and interpole coils are flash-tested at 500 volts above the final test value if they are assembled on metal spools. If not, the test is usually made when they are put on their poles, but before the poles are fitted in the shell.

The resistance of all coils is checked before they leave the Winding Department.

Coils without metal spools are checked for short circuits on the transformer apparatus.

Traction armatures and field coils are flash tested at higher voltages depending upon the rated voltage and the conditions under which the machines will operate. The tests made prior to the final may be at voltages up to 50% higher than that value.

FINAL HIGH VOLTAGE TEST.

This is applied for one minute and is in accordance with the appropriate British Standard, Table 28 (p. 174) may be taken as a summary of the several standards, with exception of that for traction machines.

Traction machines are covered by BS. 173–1941 which states that the final high-voltage test shall be of the value given by the formula 2Em + 1500 volts, where Em is the rated maximum voltage of the machine multiplied by the number of machines permanently connected in series. This test is applied between the windings and earth for one minute.

CHAPTER XXVI

INSULATION IN ALTERNATING CURRENT MACHINES

(Excluding those for Fractional Horse-Power and Turbo Alternators)

ELECTRICAL CONDITIONS IN THREE-PHASE MACHINES.

There are two ways in which three-phase windings are connected. One is known as a star connection and the other as a delta or mesh connection.

It is quite common to make motors up to about 75 h.p. suitable for either connection so that they may be connected mesh for running off 230 volts, or star for working on a 400 volt supply. Sometimes larger machines, with squirrel cage rotors, are started by special starters which connect the windings in star for starting up, and in mesh for running. No difference is made in the insulation of machines for use with these two connections.

In general, large machines are connected star; and in this country the star (or neutral) point of one alternator in each power station is connected to a good "earth." The others are run with their neutral point isolated to avoid local circulating currents of the third harmonic and its multiples. Whilst the neutral point of large motors may be earthed, it is not customary to earth that of small machines. The frames of all machines must, for the sake of safety, be thoroughly and permanently earthed.

The earthing of the neutral at the power station, and the frames of all machines has the effect of reducing the potential difference between the supply lines and earth to $1/\sqrt{3} = 0.58$ of the voltage between the lines. The advantage of this will be realised when it is stated that in consequence the maximum potential between the coils and core of an 11 kV. machine is only 6400 volts, and the insulation in the slot is based on this smaller voltage. It must be clearly understood, however, that the full line voltage exists between the phases of the winding, so that where coils of different phases are adjacent in the end winding, the insulation must be suitable for the full line voltage.

In some machines, notably turbo alternators and other high speed alternators, it is the custom to reduce the pitch of the winding to about 80 per cent of the theoretically calculated span. This has the effect of introducing coils of different phases into the same slots in such a manner as to increase the potential difference between the top and bottom half coils in some slots to more than the phase voltage, i.e., the voltage between line and neutral. Since the insulation between the half coils in each slot is at least double of that to earth, owing to it being moulded on each half, any extra voltage due to shortening the pitch is of no consequence.

If a supply system be run without earthing the neutral, and one line became earthed, full line potential would then be present between the first coils of the other phases and their slots. The normal insulation, if in good condition, should withstand the increased potential difference without trouble. Both generators and motors are normally designed for systems having earthed neutrals and the methods of insulating to be described in this and the next chapter are based upon this assumption.

HIGH VOLTAGE TESTS.

The machines dealt with in this chapter comply with BS. 168–1936 and the high voltage tests applicable are given in Table 28, (p. 174). Although BS. 168 was originally issued for machines having class A insulation, an Addendum was added in November, 1945, incorporating machines running at class B temperatures.

THREE-PHASE MOTORS UP TO 75 H.P. AND 550 VOLTS.

The stators of these motors are generally wound with round wire having a covering of double cotton, enamel and paper or synthetic enamel if for class A temperatures, asbestos or double glass covered wire being used for class B.

The type of winding chiefly used is pictured in Fig. 106. There is only one coil side per slot and it is popularly known as a single layer mush winding. Sometimes two coil sides per slot are employed, the winding then being known as a two layer mush.

For voltages up to 550 volts slot troughs of the kind employed in armatures having similar types of wire, and described in the previous chapter are suitable. The mica-presspaper trough is satisfactory for class B temperatures.

The slots of these motors are semi-enclosed, i.e., their openings are narrower than the slots, as shown in Fig. 106. This precludes the use of taped coils since the wires must be dropped through the opening a few at a time. After a coil has been inserted and wedged, its end winding may be taped. Alternate coils are taped with varnished cotton tape, with an outer protection of 7 mil cotton tape, and the others with only cotton tape. Some manufacturers prefer not to tape the end windings, but reinforce between coils with suitably shaped pieces of 0.015 in. presspaper. This reinforcement is necessary because it is usual to test between phases at 2500 volts before the stators leave the winding shop. Breakdowns between phases are likely if these precautions are

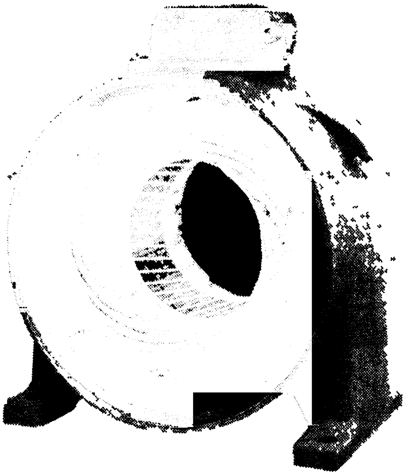


FIG. 106—Stator with three-phase mush winding. (The General Electric Co. Ltd.).

not taken. The varnished cotton tape may be omitted from windings of synthetic enamelled wire, 7 mil cotton tape alone being good enough. Seven mils cotton tape is employed because it is cheaper than 5 mils, and space is available for it.

If the winding is of the two layer type separation in the slot is effected by a strip of pressboard 0.040 in. thick and by enclosing the upper half coil in an inner liner of 8 mil presspaper. Alternatively, a length of varnished cotton tape, which is wide enough to bend some distance up the sides of the main trough, is placed on top of the pressboard separator.

The rotors for these motors are generally of the squirrel cage type. If of the slipring type the insulation of the windings is similar to that employed for armatures.

LARGER THREE-PHASE MACHINES FOR LOW VOLTAGE.

As machines increase in size, different types of windings must be employed. Large diameter round wire is not acceptable because of its poor space factor. Space factor is the ratio of the cross-sectional area of copper in a slot to the total cross-sectional area of the slot. Improvement is effected by the use of rectangular strip. It is not convenient to make coils of rectangular wire of the shape illustrated in Fig. 106. Many of the wires might become twisted so that their corners would press into adjacent conductors, and shorts would be numerous.

The use of diamond shaped coils such as are used in armatures provides a solution. These may be dropped through the slot entrance a turn at a time, or a section at a time. A section is a group of conductors taken vertically. Thus Fig. 107 shows a coil of two sections. The parts outside the slots are then taped. Adjacent coils in different phase groups receiving a layer of 7 mil varnished cotton tape before the 7 mil ordinary tape is applied.

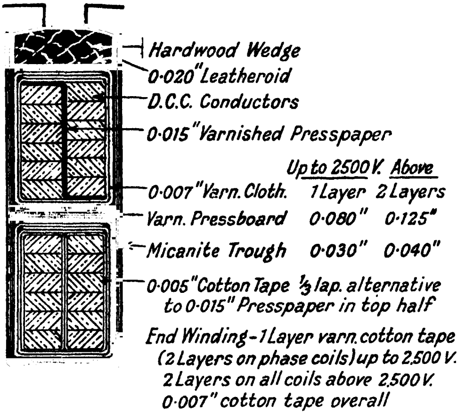

Hardwood Wedge
0·020" Leatheroid
D.C.C. Conductors
0·015" Varnished Presspaper
Up to 2500 V. Above
0·007" Varn. Cloth. 1 Layer 2 Layers
Varn. Pressboard 0·080" 0·125"
Micanite Trough 0·030" 0·040"
0·005" Cotton Tape ⅓ lap. alternative to 0·015" Presspaper in top half
End Winding - 1 Layer varn. cotton tape (2 Layers on phase coils) up to 2,500 V. 2 Layers on all coils above 2,500 V. 0·007" cotton tape overall

FIG. 107—Class "A" insulation for a semi-enclosed slot; 1,000 to 3,000 volts.

When still larger outputs demand very large copper sections the type of winding depicted in Fig. 108 is employed. This is known as a push-through winding. With such a winding, and semi-enclosed slots, all the coils must be inserted a little way along their slots at the outset. They are then pushed through a little at a time, working from one coil to another. It would not be possible to insert another coil in the stator in the photograph without pulling those already in much further back. They were pushed so far through for photographic purposes. These coils are taped with 5 mil cotton tape to give a good space factor. When pushed home the straight ends will be bent to complete the diamond shape.

To facilitate bending, the copper is laminated. The ends are joined by ferrules and soldered. Two overlapped layers of 0.020 in. thick presspaper held together with spiral tapings go between layers of the end winding. A length is visible in Fig. 108 where the lower layer of the end winding is not covered by the upper layer.

THREE-PHASE MACHINES FOR HIGHER VOLTAGES.

It is not possible to review all the ways of insulating machines to suit the many voltages in use between 550 and 11000 volts and outputs from say 100 h.p. to many thousands, but typical examples will be quoted.

A general idea of the insulation employed for machines up to

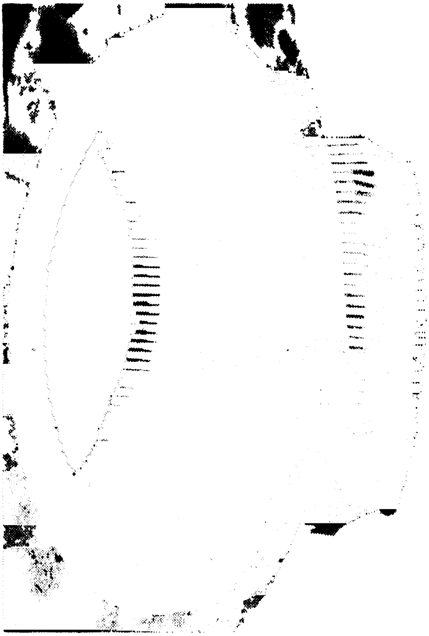


FIG 108—Push-through stator winding, 345 kw 440/460 volts, three-phase 375 rpm (The General Electric Co Ltd)

and including 3300 volts is shown by the section in Fig 107, and a view of a winding is given in Fig 109 The slot liners are increased in thickness and moulded in micanite backed with flexrope paper Their projection outside the slots increases with

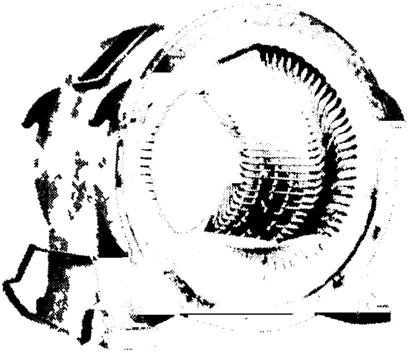


FIG 109—Diamond-type winding for stator with semi-enclosed slots 3,000 volts (The General Electric Co Ltd)

the voltage. Effective insulation between the two half coils in a slot is provided by wraps of varnished cotton cloth around each. The overhang of each coil may be taped with a layer of varnished cotton tape, with an additional layer on the phase coils. Varnished cotton tape, and mica tape when used, must always have the mechanical protection of an outer covering of 5 or 7 mils cotton tape. The insulation between layers in the end winding is dispensed with, the space between being increased by thickening up the separator in the slots and enlarging the pins around which the noses are formed.

Referring again to Fig. 107 the coils may be wound so that conductors which are side by side are in parallel. Alternatively, all turns may be in series. In such an event a fairly high voltage exists between the top two conductors, the ends of which serve as the leads of the coil; the connection between the two is made by joining together the bottom turn of each. When this is so the two sections are separated by a piece of 0.015 in. varnished presspaper as shown in the upper half, or by taping as in the lower half. In the latter case the slot entrance must be wide enough to permit the taped section to pass through.

FIG. 110—Stator wound with hair-pin coils. 1,100 h.p., 3,300 volts, three-phase, 750 rpm. (The English Electric Co. Ltd.).

The diamond type of coil is also used for large machines, the slot portions then being insulated with micanite tubes. Open type slots, instead of semi-enclosed ones, must be used for these coils.

When dealing with large machines for 3300 volts and above it is usual to insulate the end windings of all coils alike, instead of putting more insulation on phase coils than on the others. This has the effect of giving good insulation between layers in the end winding, since strip insulation, as described in connection with Fig 108 is not used

CONCENTRIC OR HAIRPIN WINDING

An alternative type of winding for large machines is shown in Fig 110, and two coils in Fig 111 This is known as the hairpin type of winding The slot portions of the coils are insulated with micafolium wrapped around and hot pressed to form what, for brevity, are called micanite tubes The coils are then pushed through the slots, the ends bent and the conductors butt welded so that all the turns are in series The overall taping may be several layers of varnished cotton or mica tape This type of coil may be employed for the largest sizes of motors or alternators

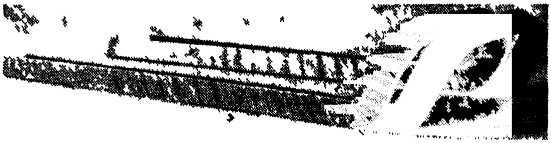


FIG 111—Hair-pin type coils for the winding shown in Fig 110 (The English Electric Co Ltd)

CORONA

The phenomenon of corona, which often shows as a blue or purple coloured haze, is liable to occur in the slots of machines, especially for voltages of 6 6 kV and above To prevent this the outside surfaces of the micanite tubes are coated with some conducting material such as graphite It might also occur between phase coils in the end winding if they are too close together However, the fact that coils are generally spaced well apart for ventilation serves to prevent it Further information on corona will appear in the next chapter

REINFORCEMENT OF TURNS

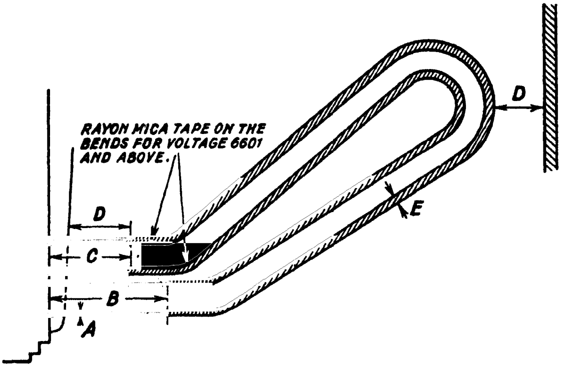
At the instant when motors are switched on to the line, the coils near the beginning of each phase receive the full impact of the voltage between their turns

To avoid breakdowns between turns under these conditions, reinforcement is added to the turns of the end coils of each phase for machines of 6 6 kV and above This takes the form of a strip of 0 010 in presspaper between turns in the slot portion and a layer of 7 mil cotton tape on alternate turns in the end winding Sometimes the strips are omitted and alternate turns taped throughout

Although alternators are not subject to shocks of this nature, since the voltage is built up gradually as they are run up to speed or by regulation of the exciting current, they may receive shocks due to surges developing in the system. For this reason the coils of alternators are reinforced in the same manner as those for motors.

A section of a slot giving details for higher voltages is shown in Fig. 112. Other details are given in Table 30. The thicknesses of tubes, layers of tape, and other dimensions may differ slightly amongst manufacturers, but the figures given represent good average practice.

Table 30—Insulation for Stator Windings.



Voltage	Mica Tube			Min. Distance to Earthed Metal i.e. Spark Distance	Layers of Silk-Mica or Yarn Cotton Tape on End Winding
	Min. Wall Thickness	Min. Extension			
		Top	Bottom		
* See fig. above	A	B	C	D	E
0— 1000	0.039	0.98	0.60	0.39	2
1001— 2500	0.055	1.38	0.985	0.60	2
2501— 3600	0.062	1.70	1.30	0.78	3
3601— 5000	0.080	2.16	1.77	0.98	4
5001— 6600	0.100	2.64	2.24	1.26	5
6601— 8000	0.120	2.95	2.44	1.42	6
8001—11000	0.160	3.54	2.95	1.73	7
11001—13000	0.177	3.94	3.46	1.97	8

* If each conductor is taped with Silk-Mica Tape reduce the wall thickness, A, by 0.012 ins. for each layer of tape.

N.B. All dimensions are in inches.

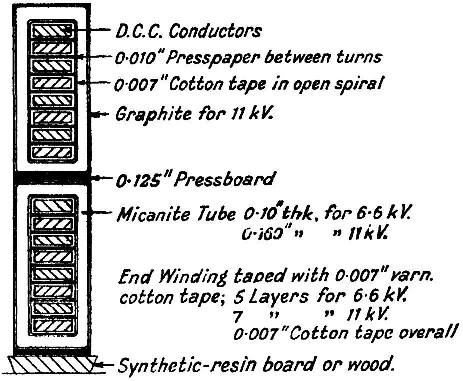

D.C.C. Conductors
0·010" Presspaper between turns
0·007" Cotton tape in open spiral
Graphite for 11 kV.
0·125" Pressboard
Micanite Tube 0·10" thk. for 6·6 kV.
0·160" " " 11 kV.
End Winding taped with 0·007" varn. cotton tape; 5 Layers for 6·6 kV.
7 " " 11 kV.
0·007" Cotton tape overall
Synthetic-resin board or wood.

FIG. 112—Class "A" insulation for an open-type slot, 6.6 kv. and 11 kv.

CLASS B INSULATION.

In all the cases already described it may be assumed that where the slot insulation contains mica it is suitable for class B machines. The conductor insulation would have to be changed to asbestos, glass, or mica tape, and mica tape used in place of varnished cotton tape on the end windings. The varnished presspaper strips between turns would be replaced by micanite.

ROTORS.

There are three types of rotors; squirrel cage, slipring and salient pole. The squirrel cage rotor usually has a winding composed of one solid bar of copper in each slot, there being no insulation between the conductors and the slots. A copper ring of ample section is used to join all the bars together at each end. The joints are made by brazing or by soldering with silver solder.

SLIPRING ROTORS.

A photograph of a slipring rotor is shown in Fig. 113. Induction and synchronous induction motors behave like transformers with an air gap, the rotor winding being the secondary. When the stator current is switched on a voltage is induced in the rotor which bears the same relation to the stator phase volts as the turns per phase in the rotor bears to the turns per phase in the stator. Hence it is possible for quite a high voltage to be induced in some rotors at the time of switching on. In fact a voltage of 2200 volts between sliprings is not uncommon, and the winding must be insulated for this voltage.

If it is a reversible motor the insulation must be designed for double the voltage across the sliprings when starting up.

The coils are sometimes of the diamond type and are dropped through the slot opening. In the majority of cases, however, they are of the push-through type like those illustrated in Fig. 108. For large rotors the winding is made up in the form of

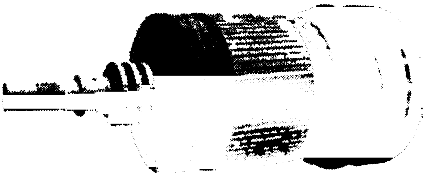


FIG. 113—A typical slipring rotor. (The General Electric Co. Ltd.).

half coils or bars. One end of the bar is formed to the correct shape on a former, the other end being left straight for pushing through the slot.

So that the push-through end may be bent easily, it is usual to make the bars of several thin strips in parallel. With this construction each bar can be pushed through to its final position at the time of insertion; there is no need to insert all of them a little way and then gradually push them home. The top and bottom layers are suitably connected together at both ends by ferrules and soldering.

The slot and conductor insulation is similar to that employed for stators of like voltage. The chief difference, particularly in the higher voltages, is that whereas in stators the distance between the top and bottom layers is purposely made large, in rotors the two layers are kept fairly close together, and mica-presspaper is inserted between. This is done to give rigidity to rotor windings so that they will withstand the compression of the steel wire bands.

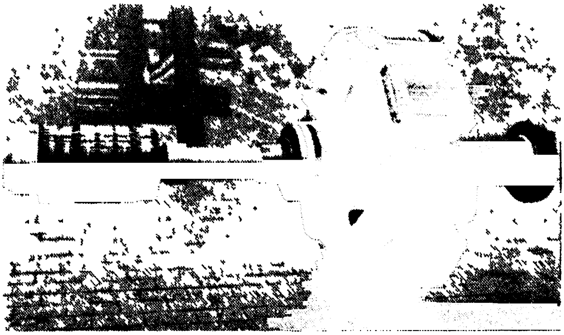


FIG. 114—A 256 kVA. 600 rpm. alternator rotor (magnet wheel), with coils wound with D.C.C. strip (The English Electric Co. Ltd.)

SALIENT POLE ROTORS.

These are used for alternators which are in general driven at not more than 1500 r.p.m., and for synchronous motors.

The coils employed are of two kinds, one type being illustrated in Fig. 114. These coils may be wound direct on to the poles, or on sheet steel spools. Details of the insulation are shown in Fig. 115 for coils wound on spools. It may be similar for coils wound direct on the poles. Many tapes must be interleaved between the turns, and each layer of the winding is thoroughly brushed with a thermo-setting synthetic resin varnish. These precautions are taken to ensure that the turns do not become displaced by centrifugal force.

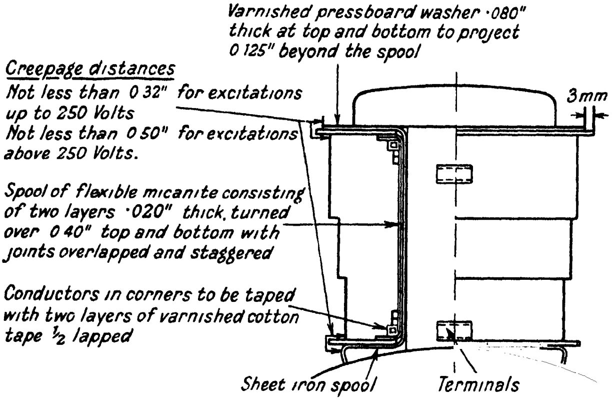

Varnished pressboard washer ·080" thick at top and bottom to project 0 125" beyond the spool
Creepage distances
Not less than 0 32" for excitations up to 250 Volts
Not less than 0 50" for excitations above 250 Volts.
Spool of flexible micanite consisting of two layers ·020" thick, turned over 0 40" top and bottom with joints overlapped and staggered
Conductors in corners to be taped with two layers of varnished cotton tape ½ lapped
3mm
Sheet iron spool
Terminals

Fig. 115—A method of insulating magnet-wheel coils wound with D.C.C. strip.

Fig. 116—Salient pole rotor for 7,500 h.p. 119 rpm. ship propeller motor. Coils wound with strip-on-edge copper. (The General Electric Co. Ltd.).

The other type of coil is illustrated in Fig. 116 and detailed in Fig. 117. These coils are known as strip-on-edge magnet wheel coils and are employed for large rotors or where high centrifugal stresses are encountered.

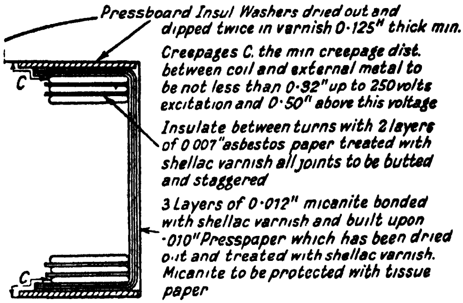

Pressboard Insul Washers dried out and dipped twice in varnish 0·125" thick min.
Creepages C. the min creepage dist. between coil and external metal to be not less than 0·32" up to 250 volts excitation and 0·50" above this voltage
Insulate between turns with 2 layers of 0 007" asbestos paper treated with shellac varnish all joints to be butted and staggered
3 Layers of 0·012" micanite bonded with shellac varnish and built upon ·010" Presspaper which has been dried out and treated with shellac varnish. Micanite to be protected with tissue paper
C
C

FIG. 117—A method of insulating magnet-wheel coils of the type illustrated in Fig. 116.

The manufacture of such coils is a lengthy process. The copper thickens at the inner edges of the curved ends, and each turn has to be filed to remove the thickening. The insulation between turns consists of two thicknesses of 7 mils asbestos paper, inserted in the form of U pieces. The legs of the pieces are of different lengths and the joints in one layer must not coincide with those in the other. They are cut wide enough to overlap the edges of the copper. The asbestos may be soaked in shellac varnish, or coated on one side with it. In the latter event the copper is coated with shellac varnish and the asbestos inserted with the coated faces adjacent.

To make these coils suitable for use they must be consolidated. This is done by assembling them in jigs to keep the turns in line, and subjecting them to heat and pressure. A jig with its coil is placed between the platens of a hydraulic press. The coil is heated electrically to 150°C. and while at this temperature the requisite pressure—usually 10 per cent above that which will be produced by centrifugal force—is applied. The coil is allowed to cool under pressure, after which the protruding insulation is cut off flush with the copper.

Each layer of the spool insulation is nicked at intervals around the curved ends to enable it to be bent outward over the top and bottom of the coil, as shown in Fig. 117. Care is taken that the cuts in one layer do not coincide with those in any other layer. As additional protection against breakdown to the poles a few turns at the top and bottom are taped together with mica tape and cotton tape.

TESTS DURING MANUFACTURE.

The high voltage tests are based on Table 28 (p. 174) which may be taken as a summary of the final high voltage tests given in the various British Standards which are applicable to these windings.

STATORS.

The high voltage tests for stators up to about 75 h.p. and 440 volts are generally in the nature of flash tests, i.e., they are applied for about ten seconds; the voltage is generally 500 volts above the final figure. It is applied after all coils are in position and connected in readiness for soldering. The same voltage is applied again when the stators are finished and ready for the assembly department.

Stators for high voltages are generally tested at 1000 to 1500 volts above the final figure. In medium sized machines it is applied after all the winding is in position and again when the stator is finished, the duration being one minute in both cases.

For very large stators each phase or pole group is tested, as it is put in, depending upon the number of coils and the capacity of the testing transformer. Further tests are made after fitting the wedges, and after connecting up.

Short circuit tests are made as described in Chapter XXII if practicable, immediately before soldering the connections and again after impregnating and finishing.

ROTORS.

Rotors are usually tested at 500 to 1000 volts above the final test voltage. The first test is made after all coils are in position; they are connected up temporarily with fine wire. A further test is made when rotors are completed. The lower voltage would apply to the smaller rotors, and would be applied as a flash test. For larger rotors the test is always applied for one minute.

MAGNET WHEELS.

Magnet wheel coils such as Figs. 114 and 116, are not pressure tested, (i.e., given a high voltage test) until they are mounted on their poles. The voltage is usually 1000 volts above the final figure and applied for one minute before, and after, tightening down.

The resistance is measured, and in the case of strip-on-edge coils (Fig. 117) an appropriate D.C. voltage is applied to each coil and the voltage between each pair of turns is checked to ensure that none of the turns are short circuited. These two tests are taken on strip-on-edge coils after the insulation between turns has been trimmed, and before the spool insulation is fitted.

CHAPTER XXVII

INSULATION IN TURBO ALTERNATORS

Turbo alternators are the greatest achievement of the electrical machinery world. From the design point of view they demand the highest skill, not only because it is necessary to work most of the materials at the greatest possible stress consistent with mechanical and electrical safety, but also because a mistake in a machine of this nature is much too expensive to contemplate. Only the most experienced workers are employed in their manufacture and it is always a pleasure to note the skill and craftsmanship they exhibit when working on these big machines.

SPECIFICATION.

These alternators are manufactured to comply with BS. 225-1925, Electrical Performance of Alternators of the Steam Turbine Type. Although this specification gives data for machines insulated for either class A or B temperatures, they are made only with class B insulation nowadays.

The final high voltage tests given in BS. 225 are reproduced in Table 31. Before the tests are made the insulation resistance should agree with that computed from the formula :—

Resistance in megohms to be not less than

$$\frac{\text{Rated volts}}{1000 + \text{Rated output in KV.A.}}$$

when measured with a D.C. voltage of about 500 volts. A 500 volt megger is generally employed for the purpose.

Table 31.—High Voltage Tests for Turbo-Alternators and Exciters.

Item No.	Machine or Part	Test Voltage (R.M.S.)
1	*Stator windings	1000 V. + twice the rated voltage (with a minimum of 2000 V.).
2	Rotor windings ...	10 times the excitation voltage.
3	Exciter Armature and Exciter Field Windings	Minimum, 2000 V. Maximum, 3500 V.

* For two-phase windings having one terminal in common, the test values indicated in this Table shall be increased by 40 per cent. ; the rated voltage shall be taken to be that of each separate phase.

TURBO ALTERNATOR ROTORS.

A finished turbo rotor is shown in Fig. 118. Apart from its general appearance of bulk and weight, which may be from about 40 tons to more than 100 tons, there is not much about a finished rotor to indicate the tremendous work involved in its manufacture.

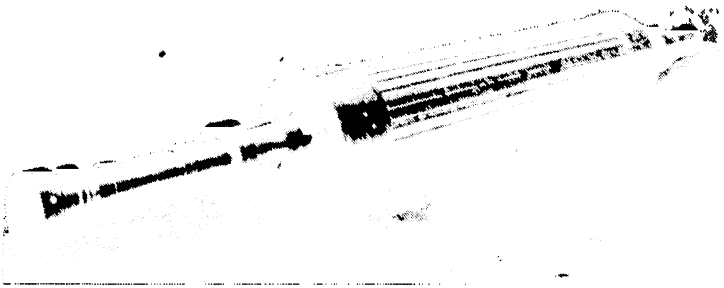


FIG. 118—A completed turbo-alternator rotor; 40,000 kVA. 3,000 rpm. (The General Electric Co. Ltd.).

As received at the works, it comprises a forging of special steel and all the slots have to be made by milling.

In Fig. 119 is seen a photograph of one end of a rotor before the end cap is pressed or shrunk on. It will be noted that the winding consists of several coils, each having many turns. All the turns in any turbo alternator rotor are connected in series, and since the excitation voltage seldom exceeds 300 volts, it follows that the voltage between turns is generally under one volt. However, micanite insulation is invariably used because these machines are run at class B temperatures; mica is also the most satisfactory medium for withstanding the tremendous compres-

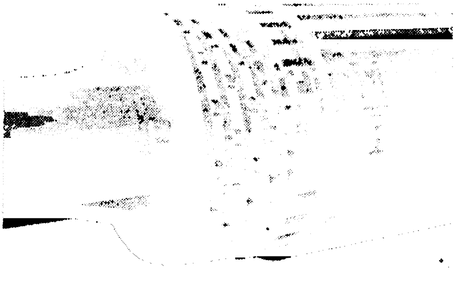


FIG. 119—View of end winding of turbo alternator rotor shown in Fig. 118. (The General Electric Co. Ltd.).

sion forces caused by centrifugal force. It may be used in the form of mica tape, if desired, for turn insulation.

When micanite is employed between turns it is in the form of strips about 36 ins. long, 0.015 in. thick and of the same width as the copper. Joints are overlapped, and staggered in the different layers to avoid local appreciable increases in depth. Curved pieces are cut out of sheet micanite for fitting at the corners. Since in the course of time dirt may collect between the coils in the end windings, several turns at the top and bottom of each coil are taped together with mica tape to prevent leakage of current between coils or to the body of the rotor.

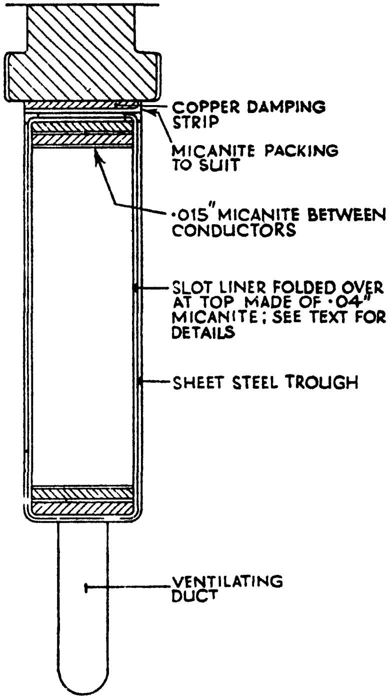

COPPER DAMPING STRIP
MICANITE PACKING TO SUIT
·015" MICANITE BETWEEN CONDUCTORS
SLOT LINER FOLDED OVER AT TOP MADE OF ·04" MICANITE; SEE TEXT FOR DETAILS
SHEET STEEL TROUGH
VENTILATING DUCT

FIG. 120—Slot insulation of turbo-alternator rotor.

ROTOR SLOT INSULATION.

There are several ways of applying the slot insulation. In small rotors micanite bonded with a flexible varnish which hardens during subsequent operations, and backed on both sides with presspaper may be employed.

More frequently, especially in large rotors, moulded micanite troughs are used. These are often moulded inside sheet iron troughs, especially if there are longitudinal ventilating ducts beneath the slots, as shown in Fig. 120. Another alternative is to use troughs of two kinds; an inner one of moulded micanite, and an outer one of backed flexible micanite, the total thickness remaining the same. The composite arrangement may be used in conjunction with sheet iron troughs.

INSERTING COILS IN ROTOR SLOTS.

The formed rotor coils are dropped into the slots a turn at a time, the inner coil of each group being inserted first. If bare strip is being used the micanite may be anchored to the copper with a spiral turn of cotton thread, or it may be dropped on the top of each turn in the slot. Everything is so proportioned that the copper is fairly tight across the slot and it is usual to have to knock each turn down on to the one below.

It is important to avoid the copper becoming slack in the slots during service. This would occur if the bond in the insulation were to soften and flow. To prevent this the whole winding, after being connected up, is heated electrically to a much higher temperature than it will attain in service. Heavy steel bars are fixed on the top of every coil and pressure is applied by the screws in the rings seen in Fig. 121. Immediately after this operation the insulation liners are folded over on the top of the coils.

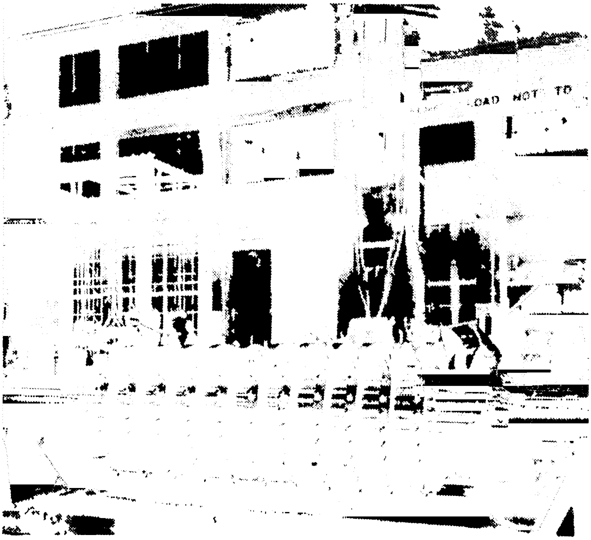


FIG. 121—Pressing the coils in a turbo-alternator rotor. (The General Electric Co. Ltd.).

PRESSING ROTOR END WINDINGS.

After the wedges have been inserted and the packing blocks put between the ends of the coils, the winding is again heated and the ends are pressed to the true shape. The packing blocks may be of bakelised asbestos or fabric. Asbestos tape is generally employed where overall taping is needed for holding insulation in position. The winding is insulated from the steel end rings by layers of micanite and leatheroid, the latter being on the outside to permit the rings to slip over without damaging the micanite.

TURBO ALTERNATOR STATORS.

Visitors to works where these are made will invariably stop and admire the beautiful symmetry of a turbo-stator winding and the craftsmanship employed in making it, but what can be seen of a finished winding is only a small part of the total work involved in its manufacture.

These windings fall into two groups. One is known as a diamond or basket type winding and is illustrated in Figs. 122 and 128.

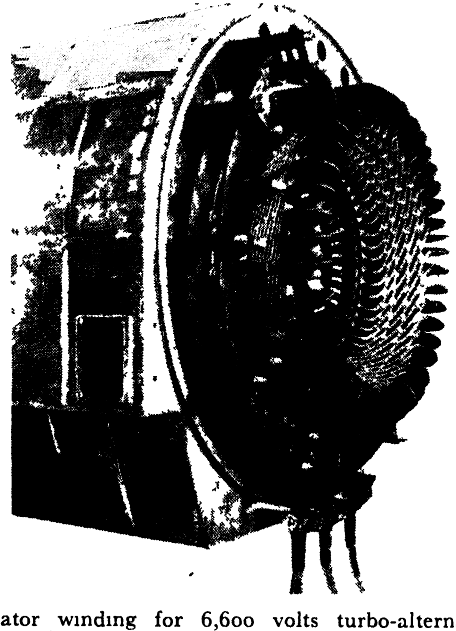


FIG. 122—Stator winding for 6,600 volts turbo-alternator, insulated throughout with mica-paper tape. (The British Thomson-Houston Co. Ltd.).

The other, known as a concentric winding, has an appearance somewhat like the push-through winding illustrated in Figs. 110 and 131. It is often more complicated than the first one referred to as there may be two or more coil sides per slot. Also, because of the much greater size, it is usual to make the slot portions as straight bars, the curve ends as separate items, and connect them together after the bars have been put in their slots. This construction was used in Fig. 131. The same methods of applying the insulation are applicable to both types of winding, and since the diamond type is more frequently made than the concentric, the descriptions will deal with the insulation of diamond coils.

INSULATION OF TURBO STATOR COILS.

Some idea of the complexity of these coils may be obtained from an examination of Figs. 123 and 124. In the former section two half-coils are shown. The separate strips of copper are known as sub-conductors. For reasons which cannot be given here, it is necessary for the sub-conductors to be insulated from each other. If the section of copper is not too great it may be covered with an asbestos or fibrous glass covering. For larger sections there are several alternatives :—

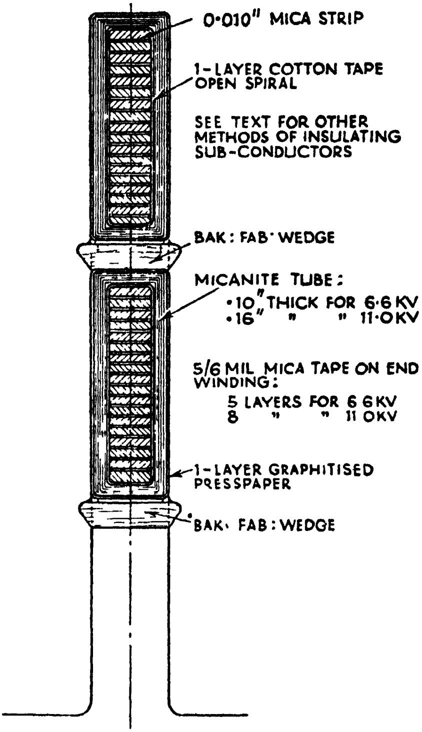

0·010" MICA STRIP
1-LAYER COTTON TAPE OPEN SPIRAL
SEE TEXT FOR OTHER METHODS OF INSULATING SUB-CONDUCTORS
BAK: FAB· WEDGE
MICANITE TUBE:
·10" THICK FOR 6·6 KV
·16" " " 11·0 KV
5/6 MIL MICA TAPE ON END WINDING:
5 LAYERS FOR 6 6 KV
8 " " 11 OKV
1-LAYER GRAPHITISED PRESSPAPER
BAK· FAB: WEDGE

FIG. 123—Insulation of slot portions of turbo-alternator stator coils for 6.6 and 11 kV.

1. As Fig. 123, viz. 0.010 in. micanite between sub-conductors in the slot portion, and lapped rayon-mica-paper tape on alternate sub-conductors in end winding.

2. Paper-mica-paper tape (6/7 mils) ⅝ lapped on alternate sub-conductors
3. Paper-mica-paper tape (6/7 mils) ⅓ lapped on every sub-conductor
4. Asbestos or fibrous glass sleeving on all sub-conductors, or alternate ones if convenient

Whilst the ideal winding has only one turn per coil, as illustrated in Fig 123, electrical conditions may necessitate the use of two or more turns per coil In such cases the sub-conductors may be insulated in any of the ways just described, each group forming a turn being insulated with one or more layers of mica tape This arrangement is clearly depicted in Fig 124, where each group of three sub-conductors is taped to form a turn, there being three turns in the coil

The data given in Table 30 on page 217 apply equally well to turbo alternator coils so far as electrical conditions are concerned

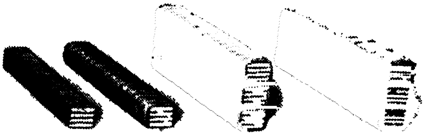


Fig. 124—Stages in the making of multi-turn turbo-alternator stator coils. (The British Thomson-Houston Co. Ltd.).

Physical considerations sometimes necessitate increases in the length of the projections of the slot portions of the coils.

Consolidation of Slot Portions of Coils.

Whatever system of insulating is employed it is usual to hot press the slot portions of the coils and consolidate them before proceeding with the application of the overall insulation. Fig. 125 is reproduced from a photograph of a half-coil being steam pressed. Steam is admitted to the base of the press, and is at such a pressure as to heat the press to at least 150°C. When this temperature has been maintained for the requisite time, ½ hour for the first pressing, and up to 2 hours for subsequent mouldings, the steam is shut off and cold water is run through to cool the mould as quickly as possible. Even so, it will take from one to two hours to cool down, and the mechanical pressure must not be released until the mould is cold.

Overall Insulation of Coils.

Two methods are available for applying the overall insulation. One is to apply layers of paper-mica-paper tape from end to end of each half-coil, the tape being made with a bitumastic bond. This type of insulation is shown in Fig. 124. The tape goes from end to end and is applied by hand. When a few layers have been lapped on a number of half coils they are put into a chamber and subjected to a vacuum of about ½ in. of mercury for some time, after which high melting point bitumen is admitted to the chamber and forced into the taping with a pressure of 80 or 90 lbs./sq. in.

After removal from the impregnator the half coils are steam pressed before further layers of tape are added and the whole process again repeated. A stator winding having coils insulated in this manner is shown in Fig. 122.

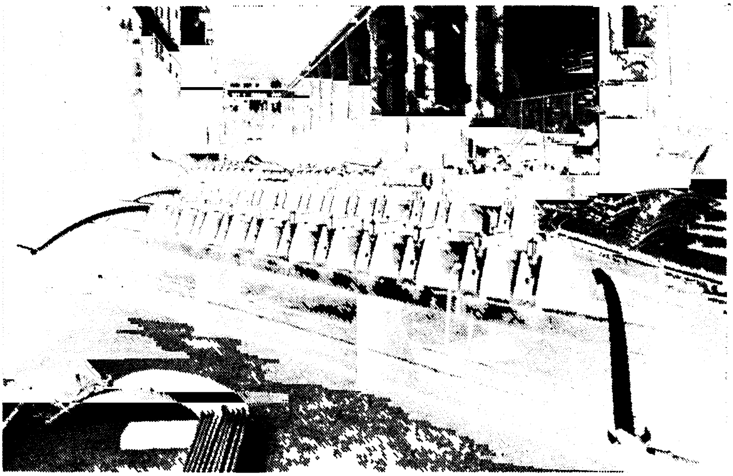


Fig 125—Steam-pressing turbo-alternator stator coils (The General Electric Co. Ltd).

In the second method the slot portion is insulated with micafolium bonded with a bitumastic varnish and the ends taped with mica tape. The starting edge of the micafolium is stuck to the coil and enough is wrapped round the coil to give the requisite finished thickness for voltages of 6.6 kV and below; for 11 kV the total thickness is put on in two operations.

IRONING MICAFOLIUM ON THE SLOT PORTIONS OF COILS.

It is not possible to apply this wrap tightly by hand and mechanical means have to be employed. This is accomplished by putting the half coil in an ironing machine of the type shown in Fig. 126. In this machine it is held stationary under tension by vises which grip it at each end of the slot part. Two long electrically heated irons are pressed on the coil by springs and made to move round it. The end of one iron is indicated by the letter A in the photograph and a diagram of the mechanism is given in Fig. 127.

The heat from the irons softens the bonding varnish, and their friction and rotation pull the wrap round until it is tight. It is so effective that the outer layer of paper will make at least two

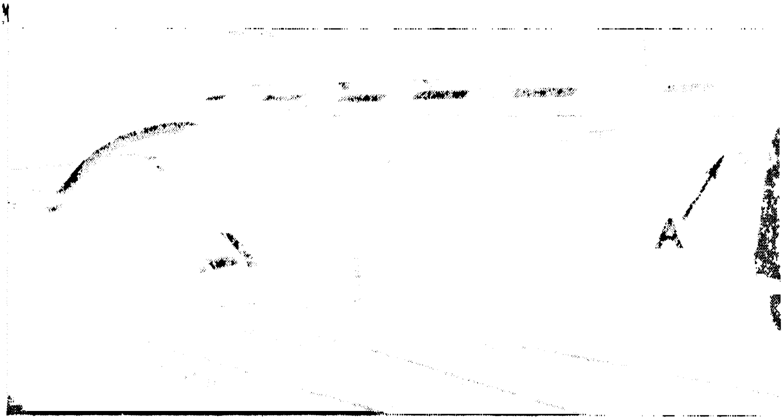


FIG. 126—Machine for ironing the micafolium wraps on turbo-alternator stator coils. (The General Electric Co. Ltd.).

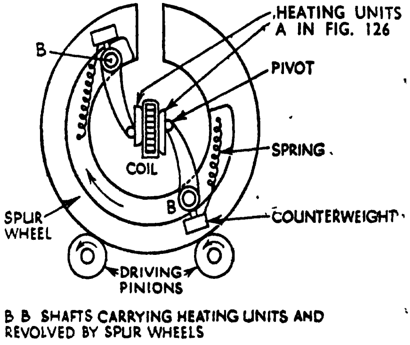


FIG. 127—Mechanism for ironing the wraps of turbo-alternator stator coils.

complete revolutions before the wrap is fully tight. The time taken to accomplish this is about half an hour. When tightening is complete the half coil is removed and put into a hand operated box mould where it is allowed to cool and solidify in readiness for the steam press. Steam pressing is carried out in the manner already described.

If the coils are for 11 kV the first tube is made less than the full length of the slot portion. Its ends are tapered and a number of layers of mica tape are lapped on, extending from the ends of the tubes for some distance along the curved ends, where they are gradually tapered off. The number of layers is such that when the slot portion is pressed they will have a thickness equal to that of the first tube. Micafolium to make a second tube, and of the full length is then wrapped on, ironed, cold pressed and steam pressed. The complete taping of the ends is then carried out.

CONNECTING COILS IN THE STATORS.

After all the half coils have been assembled in a stator, the sub-conductors at one end are suitably joined by silver soldering to convert half coils into whole coils. At the other end they are suitably connected to make turns in multi-turn coils, or joined to the next coil or cross connector as the case may be. Each sub-conductor is insulated from its neighbour at joints by taping or the interposition of micanite strips.

MAKING THE WINDING RIGID.

Tapered blocks, clearly visible in Figs. 122 and 128 are wedged between the slot portions of the coils which are outside the core. These, and the blocks in the end winding are of hardwood, or synthetic resin paper board and are held in position by string bands. The whole arrangement is designed to prevent movement of the winding if larger forces come into play because of a short circuit.

FIG. 128—Turbo-alternator stator winding; 30,000 kVA., 11.8 kV., 3,000 rpm. Slot insulation ironed and pressed as illustrated in Figs. 125 and 126 and end winding insulated with rayon mica tape. (The General Electric Co. Ltd.).

Tests During Manufacture.

ROTOR WINDINGS.

According to Table 31 the final high voltage test is 10 times the exciter voltage. High voltage tests during manufacture are carried out at 500 volts higher. They are made after the coils are pressed and again when the rotors are finished.

STATOR WINDINGS

The soundness of the insulation between the sub-conductors is tested with a 230 volt supply, a lamp being employed to limit the current in case of a fault being present. The test is generally applied during the first pressing to consolidate the slot portions of coils, and after subsequent pressings. It is finally applied after the coils have been wedged in their slots, *i.e.*, immediately before the various connections are made.

The high voltage tests are based on Table 31. In the case of an 11 kV winding each phase group of coils, or half coils according to circumstances, is tested at 25 kV as soon as they are put in the slots. They are next tested at 24 kV after being wedged in the slots and the end windings fastened down. A final test at 24 kV between phases and to earth is made after the completion of the winding.

The voltages for corresponding tests of a 6.6 kV stator would be 15 kV and 14.5 kV.

CHAPTER XXVIII

HIGH VOLTAGE PHENOMENA; THE INSULATION OF TURBO-ALTERNATORS FOR 22 kV AND ABOVE

HIGH VOLTAGE PHENOMENA.

When windings are undergoing their high voltage tests certain manifestations occur which are apt to alarm those who only occasionally witness such tests. These may be streamers extending from the winding to prominent points on nearby metal; there may be brush discharges from slight prominences on the coils, or there may be intense corona at certain places, particularly where the coils leave their slots.

Well designed machines for 11 kV will not exhibit these discharges at working voltage, provided earthing shields are used on the slot portions of the coils. They may, however, be present at the test voltages, but since tests at these high voltages are not made after the machine has been put into service it is not usual to spend money in trying to eliminate them, unless they are very bad.

Those who are responsible for supervising tests of this nature in the works are fully aware of the implications of such phenomena, and whether or not they indicate future trouble. It is quite safe in case of doubt for a visiting inspector to be guided by the opinion of the supervisor in charge of the test, since the latter has nothing to gain, and usually much to lose, by giving incorrect advice. Firms which make large and expensive machines do not like the expense and worry of defects developing in them after delivery.

In high voltage alternators these phenomena would occur at working voltages if steps were not taken to eliminate them. These will shortly be described.

CORONA AND ITS EFFECT UPON INSULATION.

Reference was made in the previous chapter to corona occurring in the slots of machines. In general it cannot be seen, but may be indicated by a slight hissing sound if the voltage is switched on to a winding in a perfectly quiet building. If the machine is running its presence may be indicated by a faint smell of ozone.

Corona destroys vegetable matter, such as paper, tape, etc., upon which it impinges. This destruction is a slow process and it may take many years for its effect to be of serious consequence, although its presence may be suspected long before positive evidence is found.

The photograph which is reproduced in Fig. 129 is of especial interest. It is of a piece of 0.010 in. presspaper liner removed after fifteen years' service in the slot of an 11 kV generator. The parallel, irregular, white lines show where corona has completely destroyed the material, the white being due to illumination at the back showing through the holes.

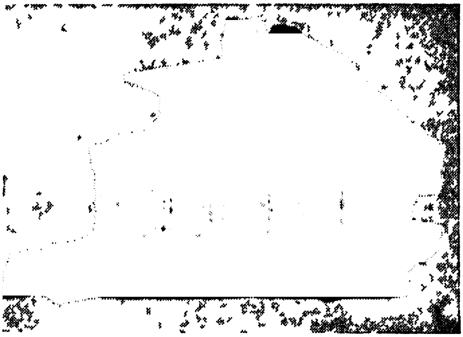


FIG 129—Effect of corona on 0.010 in presspaper, removed after 15 years in an 11 kV. stator.

Fortunately corona has no effect upon mica so that the destruction ceases as soon as the outer layers of vegetable matter have disappeared and the corona comes to the mica splittings in the micanite tubes. It is no doubt because of this that machines made as long ago as 25 years are still functioning perfectly, and seem likely to continue doing so, in spite of the smell of ozone which they continually emit. The machine from which the sample was taken had not broken down because of the corona, a fault of a totally different kind had developed.

The elimination of corona in slots is a simple matter. The outside of the tubes may be taped with asbestos tape which is thoroughly impregnated with graphite, or the outer wrap may consist of presspaper coated with graphite, or colloidal graphite may be painted on the outside of the tubes.

TURBO ALTERNATORS FOR 22 kV AND 33 kV.

Unless special precautions are taken intense corona, and perhaps streamers, will be present in these machines at working voltages. Whilst it is not convenient to disclose details of the methods employed in every case for their elimination, it will be of interest to describe the details as far as possible, and for the rest to indicate the problems that have to be solved.

For 33kV alternators two manufacturers have adopted circular conductors made up in the form of a three-core cable, and resting in circular slots. The insulation between each core, and between the outer core and the slot is of mica paper, the thickness of each dielectric being ample for one-third the voltage between line and neutral. Thus the innermost core, or "bull" is insulated from earth by a total thickness of insulation which is adequate for the full voltage to earth.

In connecting up this winding all the bull conductors in a phase are connected in series, all the intermediate or "inner," cores in a phase are also connected in series, and so are all the "outer" conductors of a phase. The appropriate ends of the bull and outer conductors are connected to the line and neutral terminals respectively. The other ends are connected to the free ends of the "inner" conductors in such a manner that there is a uniform drop in voltage throughout the phase. By this means the electrical conditions between coils and slots are made equivalent to those obtaining in an ordinary 11 kV alternator.

Other makers have retained one or other of the orthodox types of winding, *i.e.*, they have either used the diamond type of winding as illustrated in Fig. 130, or the concentric type as Fig. 131. In some respects both types experience similar electrical conditions, and it will simplify things by confining the explanation to one voltage and type. Consideration will therefore be given to a 22 kV stator having a diamond type of coil, such as Fig. 130.

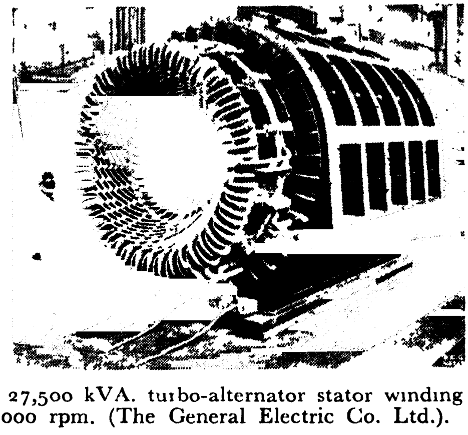


FIG. 130—A 27,500 kVA. turbo-alternator stator winding for 22,000 v. 3,000 rpm. (The General Electric Co. Ltd.).

One of the most important points to remember is that sharp corners produce a concentration of electric stress and must be avoided. For this reason the top and bottom sub-conductors in the coils are provided with ample radii, and the corners of the micanite tubes are well radiused.

Electrical insulation is a poor conductor of heat, and it has been necessary to improve the quality of that used in high voltage machines, so that the thickness for say a 22 kV machine is much less than double that employed for 11 kV.

FIG. 131--Stator winding of the "concentric" type. 71,428 kVA., 33,000 volts, 1,500 rpm. three-phase. Metropolitan-Vickers Electrical Co. Ltd.).

THE PREVENTION OF CORONA.

The prevention of corona in the slots, as has been stated, is a simple matter. However, the elimination of discharges from the ends of the slots, and other parts of the windings, is not so simple.

The state of things at the ends of the slots, before precautions are taken, may be pictured as in Fig. 132 (A) where corona is shown extending from the ends of the slots for some distance along the tubes. It also fills the space between the tubes and the clamping fingers. By extending the earthing shields on the slot portions of the tubes the discharges may be removed from the ends of the slots, and the spaces between the coils and the fingers. The condition will then be as shown in Fig. 132 (B), the corona then being at the end of the earthing shields, *i.e.*, at *c*.

The presence of discharge is an indication that the air is over-stressed. It is not possible here to analyse fully the conditions existing in Fig. 132, they are too complex. However, an elementary consideration of the problem may be of interest. Suppose *a* is a point on a conductor which is connected to one of the line terminals Since the earth shield is of low resistance it may be assumed that the potential at *c* will be the same as at *d*, namely earth potential Then the voltage drop between *a* and *c* through the insulation to *b*, and through the air from *b* to *c* will be $L/\sqrt{3}$, where L is the line voltage If it could be arranged for some of the drop in voltage to occur between *c* and *d*, it might be possible to reduce that between *b* and *c* to below the gradient at which any sort of discharge would occur

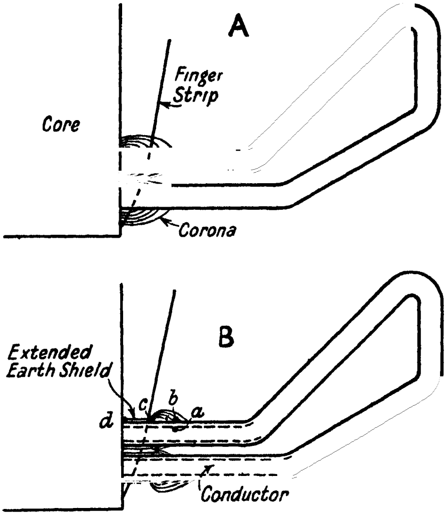


FIG 132—Diagrammatic representation of corona on high-voltage stator coils

Now, the current I, which charges the stressed air to the right of *c* flows through the earth shield from *c* to *d* If this part of the shield could be made to have a resistance R, the voltage drop V from *c* to *d* would be IR Hence, by making R suitably large the voltage drop V between *c* and *d* may be raised to such a value that the drop between *a* and *c* (viz $L/\sqrt{3}-V$) would be too small to cause overstressing

There are other methods of re-distributing the stress so as to avoid discharges One is by the use of capacitance shields These are the same in principle as condenser bushings They must be applied to the outside of the insulation and extend from the slot ends for a suitable distance towards the end winding

Insulation of the requisite thickness for these voltages is applied in several stages, each stage being impregnated and pressed, or ironed and pressed, depending upon the type of insulation. The distribution of the electrical stress may be suitably controlled by inserting conducting sheaths between each section of insulation, these being proportioned in length to equalise the longitudinal gradient where the coils leave the core.

In the end winding the full line voltage is present where phases are adjacent. Here it is necessary to employ suitable reinforcement to prevent failure of the insulation, at the same time taking care to ensure that the distance between phases is too great for discharges to occur. It should be noted that if sparking is occurring between two insulated conductors, which have an air space between them, adding more insulation will not prevent the trouble, unless the whole of the space is made up solid with insulation. If the effect of adding insulation is merely to reduce the air space between the conductors the discharge in the smaller space will be more intense than across the original.

The increase in the discharge across the shorter air space is explainable in this manner. Between the two conductors there are several dielectrics in series, those on the conductors having a fairly high permittivity (dielectric constant), and the air with permittivity of 1.

When a stress is applied to dielectrics in series, the voltage distribution is governed by the permittivity and the relative thickness of each dielectric—it is inversely proportional to the former and directly proportional to the latter. Thus if the conductor insulation is increased at the expense of the air, the voltage across the latter will certainly be reduced, but not in proportion to the reduction in thickness, owing to this difference in permittivities. The stress in the air will actually be increased and the discharge will be fiercer.

TESTS DURING MANUFACTURE.

There is not a British Standard for machines of these voltages. In consequence interested parties have to agree as to the final high voltage tests. The generally accepted figure is based on the formula in BS. 225 viz.

2 × working voltage + 1000 volts, applied for one minute.

The tests during manufacture follow the lines of those for 11 kV machines. As voltages increase so does the stress on the insulation nearest the conductors. It is therefore important to apply the minimum number of high voltage tests consistent with ensuring absolute reliability.

Whilst all tests of this nature should be applied for not less than one minute care should be taken not to greatly exceed sixty seconds, as long applications may cause incipient failures.

ROTORS FOR HIGH VOLTAGE TURBO ALTERNATORS.

These are identical with the rotors used for lower voltages and are tested as previously described.

THE END

APPENDIX A

CONDITIONING SAMPLES AT 65% RELATIVE HUMIDITY

(From Appendix A BS 633-1935)

The specimens shall be subjected to a controlled atmosphere at a temperature between 21°C and 22°C (70-72°F), relative humidity 65 per cent Whenever possible the specimen shall be tested without removal from the conditioning atmosphere If it is impracticable to test the specimen in the conditioning chamber, the test may be carried out in an atmosphere the relative humidity of which is between 65 per cent and 70 per cent

The specified relative humidity may be obtained by the use of a solution of calcium chloride in water, specific gravity 1 29 at 15°C * Sulphuric acid shall not be used for obtaining the specified relative humidity The surfaces of the calcium chloride shall be large per unit volume of air space otherwise the rate of attainment of equilibrium is very slow

To ensure that the relative humidity of the controlled atmosphere is maintained at the correct value, it is necessary either that the temperature be kept very constant or that the air be circulated within the chamber

The following method has been found satisfactory in maintaining the relative humidity of the controlled atmosphere constant —

The specimens are suspended separately in a cubical metal box with sides 24 inches long The floor of the box is nearly covered by a dish containing calcium chloride Air is circulated by means of a small fan over the calcium chloride up through holes cut at two corners of the shelf over the samples and down through holes at the opposite corners of the shelf

The humidity of the air, which may be measured by wet-and-dry-bulb thermometers if the velocity of the air past them is greater than three metres per second, attains a constant value, unless the prevailing conditions are extreme, in about three minutes after the box has been closed and the fan has been started As an alternative to wet-and-dry-bulb thermometers which require a known air velocity, a dew point thimble may be inserted in the box and used when the fan is not working With either method a window is necessary to avoid opening the box

The correctness of the humidity of the air should be checked from time to time

---

* This density corresponds with a concentration of 30 3 grammes anhydrous calcium chloride in 100 grammes of solution

APPENDIX B

CONDITIONING SAMPLES AT 75% RELATIVE HUMIDITY

(From Appendix A. BS. 1314-1946)

The specimens shall be subjected to a controlled atmosphere of relative humidity 75 per cent (± 2 per cent) at a temperature of 20°C. (± 2°C.), for not less than 18 hours. Every specimen shall be tested as soon as possible after removal from the controlled atmosphere, and in any case the test shall be started before three minutes have elapsed.

The specified relative humidity may be obtained by the use of sodium chloride, which must be sprinkled with water occasionally. The surface of the sodium chloride must be moist, but care must be taken that it is not flooded with water.

Sulphuric acid shall not be used, as there is a risk that fumes from the acid may injure the specimens in the conditioning chamber.

To ensure that the relative humidity of the controlled atmosphere is maintained at the correct value, it is necessary either that the temperature be kept constant or that the air be circulated inside the chamber. The surface of the sodium chloride should be large per unit volume of air-space, otherwise the rate of attainment of equilibrium is very slow.

The following apparatus has been found satisfactory for maintaining the relative humidity of the controlled atmosphere constant.

The chamber consists of a cubical box with sides 24 in. long. The floor of the box is nearly covered by a tray containing lumps of sodium chloride, which are occasionally sprinkled with water as indicated above. The samples of material to be conditioned are placed on a shelf half-way up the box. Air is circulated by means of a small fan over the tray, up through holes cut at two corners of the shelf, over the samples and down through holes at the opposite corners of the shelf.

Unless the prevailing conditions are extreme, the humidity of the air attains a constant value in about three minutes after the box has been closed and the fan started.

If the velocity of the air is greater than three metres per second, the humidity may be measured by wet-and-dry-bulb thermometers. As an alternative to wet-and-dry-bulb thermometers, which require a known air velocity, a dew point thimble may be inserted in the box and used when the fan is not working : with either method a window is necessary to avoid opening the box.

NOTE.—The use of common salt is not permitted for obtaining the specified relative humidity, because there may be an ingredient in common salt which alters the relative humidity obtained. It is therefore necessary to insist upon the use of sodium chloride.

APPENDIX C

CONDITIONING SPECIMENS AT 95% RELATIVE HUMIDITY

(From Appendix C. BS. 634-1935)

The specimen shall be subjected for 18 hours to a controlled atmosphere, relative humidity not less than 95 per cent at a temperature between 15°C. and 25°C. The electric strength shall then be determined at 20°C. whilst the specimen is in the controlled atmosphere.

The specified relative humidity can be obtained by the use of an air-tight enclosure containing a large surface of water, the enclosure being lagged to prevent rapid changes in temperature. It is usually necessary to use a fan to circulate the air.

APPENDIX D

ELECTRODES FOR USE IN TESTING SHEET MATERIAL

METHOD OF CARRYING OUT THE TEST

(From Appendix C. BS. 1137-1943)

The upper electrode shall consist of a solid cylinder of brass $1\frac{1}{2}$ in. in diameter and $1\frac{1}{2}$ in. high. The lower electrode shall consist of a brass block of 3 in. diameter and 1 in. thick (see Fig. 133). The sharp edges shall be removed from the electrodes, but the radius at the edge shall not exceed $\frac{1}{32}$ in.

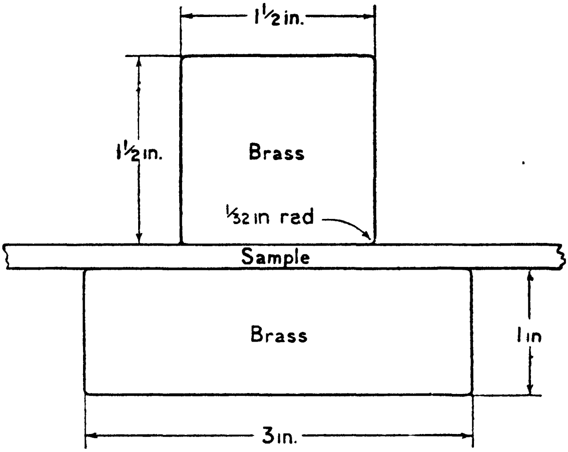


FIG. 133—Electrodes for electric strength (Proof) test.

When the surface of the specimen is irregular or any difficulty is experienced in obtaining good contact, it is recommended that tinfoil should be interposed between the electrodes and the specimen.

The test shall be carried out as follows:—

The test shall be made with alternating voltage of a frequency of about 50 cycles per second, and the specified test voltage shall be applied between the electrodes.

The test voltage shall be of approximately sine wave form, and during the application of the test the peak value as would be determined by spark gap,* by oscillograph or by any other approved method, shall be not more than 1.45 times the r.m.s. value. The r.m.s. value of the applied voltage shall be measured by means of a suitable voltmeter connected to the output side of the testing transformer, by means of a voltmeter used with a suitably calibrated voltage transformer or by means of a voltmeter used in connection with a special calibrated voltmeter winding on the testing transformer.

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* For spark gap dimensions, see British Standard Rules for the measurement of voltage with Sphere-Gaps, British Standard Publication No. 358.

The test shall be commenced by applying one-third of the specified proof stress between the electrodes, and the voltage shall be increased at the rate of approximately 1 kilovolt per second to the appropriate proof stress. The proof stress shall then be maintained for one minute.

APPENDIX E

METHOD FOR DETERMINATION OF CONDUCTIVITY (RESISTIVITY) OF AQUEOUS EXTRACT

(From Appendix M. BS. 698-1936)

The paper or other material shall be cut into strips about 20 mm by 3 mm. One gramme of the strips and 100 millilitres of distilled water shall be put into a round bottomed high grade resistance glass or quartz flask, fitted with a "ground-in" reflux condenser of either the same quality glass or quartz. The water shall be boiled for one hour, care being taken not to char the specimen.

The distilled water used for the test shall have a conductivity not exceeding 2* (a resistivity not less than 500,000 ohms) per centimetre cube. The conductivity (the resistivity) of each batch of distilled water shall be determined. A blank test shall be carried out before each extraction by boiling at least 100 millilitres of the distilled water in the extraction apparatus for not less than one hour and then testing this water for conductivity (resistivity) as described below. The conductivity of the "blank" shall not exceed 2 (the resistivity not less than 500,000 ohms) per centimetre cube. If the distilled water does not comply with this requirement, further blank tests shall be carried out, and if the result is still unsatisfactory the flask shall be discarded.

The conductivity (the resistivity) of the distilled water, "blank" and aqueous extract of the specimen material shall be determined at 20°C. (or corrected to 20°C.) by means of a suitable cell and an alternating current bridge with a frequency of 800 to 1000 cycles per sec. or an ohmmeter or other suitable measuring apparatus. If the test is carried out with direct current, the reading of the instrument shall be taken within five seconds of the application of the voltage, which shall be not less than 100. The cell shall be calibrated by means of a test made on a solution of known conductivity (resistivity).†

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* The unit in which conductivity is expressed = 1/megohm per centimetre cube.

† Information as to where a suitable calibrated cell can be procured may be obtained from the Director of the British Standards Institution, 28 Victoria Street, London, S.W.1.

Appendix F

METHOD FOR THE DETERMINATION OF THE EFFECT OF OIL

(From Appendix VII, BS. 119-1930)

The test for the ability of the varnish to resist the action of oil shall be carried out on a coil of copper wire, which shall be wound, dried and impregnated with varnish, as described below. The coil employed for the test shall be of circular section, approximately 2 inches internal diameter and 2 inches long. The coil shall be wound to a depth of approximately ½ in. with double cotton-covered wire, 0.036 inch diameter. Before the application of varnish, the coil shall be dried for six hours in an oven at a temperature between 95°C. and 100°C. It shall then, whilst still hot, be dipped in the varnish under test and allowed to remain immersed until all bubbling ceases. The coil shall be removed from the varnish, allowed to drain, and shall then be baked for eighteen hours at the temperature recommended by the varnish-maker, but not exceeding 110°C.

The impregnated coil shall be immersed in insulating oil complying with British Standard Specification No. 148 for Class A oil, at a temperature between 105°C. and 110°C. for twenty-four hours. The coil shall then be removed from the oil, and when cool shall be dipped several times in clean petroleum spirit.

The varnish on the coil shall not be appreciably affected.

The oil in which the coil has been immersed shall be compared with similar oil which has been subjected, with no immersed coil, to the same heat treatment. There shall be no noticeable difference in sludging properties.

In the event of there being any doubt as to interaction between the oil and the varnish, the oil in which the coil was immersed and the oil which has been heated alone shall be tested for sludge, the test being carried out in accordance with the method described in British Standard Specification No. 148 Insulating Oils for Electrical Purposes.

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